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Research Article

Investigation of production conditions of interstitial-free steels in electric arc furnace

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Abstract

The iron and steel industry has had a strategic importance throughout history. In recent years, with the development of technology and sectoral competition, new investments have been investigated. One of them is Interstitial-Free (IF) steels. Interstitial-Free Steel, containing very small amounts of carbon and nitrogen, is used in the production of automotive interior and exterior panels. IF steel structures have high formability. This feature has been obtained by removing interstitial atoms such as C and N in vacuum degassing method. In addition, remaining of these elements can be stabilized in steel by adding Ti and/or Nb. After the steel production process is completed, the slab is heated to a certain temperature in the heating furnace. The finishing and coiling temperatures are also important factors in determining the deep-drawing capability. These parameters help in obtaining the coarse TiC and NbC precipitates and the high r value, which is an important indicator of fine-grained structure, high ductility and formability. In this study, the effect of process parameters on IF steels in electric arc furnace steel production, secondary metallurgy processes and hot rolling are explained. Also, the effect of microstructures of steel samples with different chemical compositions and thicknesses on mechanical properties was investigated. In addition, the samples taken from the hot rolled coil were examined under scanning electron microscope (SEM), and texture analysis was performed with electron backscatter diffraction (EBSD) technique. Particularly, the microstructure investigations have shown that Ti and/or Nb is the critical element in terms of ensuring the formability, so interstitial atoms are not formed.

Keywords

Continuous Slab Casting; Electric Arc Furnace; Hot Rolling; IF steels; Ladle Furnace; Metallurgy

1. Introduction

The term 'interstitial steel or IF steel' means that there are no interstitial atoms (C and N) in the lattice structure and the resulting steel is mild steel [1]. Thus, it is prevented that the precipitates inhibit the movement of grain boundaries during recrystallization [2].

IF steels have a body-centred cubic (bcc) crystal lattice structure, have a ferrite phase. The ferrite grain size in the structure affects the yield strength, ductility and strain hardening exponent (n). The main properties of these steels are low yield strength, high plastic anisotropy ratio (r value), low aging property, good deep drawing and good formability. After hot deformation, cold rolling and annealing, a recrystallization texture {111} is formed, where high deformation occurs. This type of texture allows high levels of r, which is associated with good formability of ultra-low carbon [1].

2. Production of IF Steels

2.1. Steel Production in Electric Arc Furnace

Steel melting takes place in an electric arc furnace. Scrap (HBI, Pig iron and DKP) is used as charging material. The most basic task of the furnace is to facilitate the next processes by providing rapid melting. After the scrap charge is transferred to the furnace, the furnace door is closed and the electrodes form an arc in the furnace with the voltage given by the system. Oxygen and carbon are blown from the burners and then the steel is refined. After the steel melting process is completed, impurities are formed and lime, pyramid Al, ferromanganese are added to remove these impurities from the steel and take them into the slag. Due to the high temperatures reached in the electric arc furnace, phosphorus is removed from the steel by binding to the slag with lime. The amount of sulphur is reduced from 0.080 - 0.090% to 0.010 - 0.008%.

$$2P + (5FeO) + 3(CaO) = 3CaO.P_2O_5 + 5Fe \quad T < 1570^{\circ}C \quad (1)$$

After the scrap smelting and refining processes are completed in the electric arc furnace, it is time for the tilting process. The purpose of tilting is to separate slag and steel from each other. The slag taken from the furnace is sent to the slag plant, while the steel is sent to the ladle furnace. Casting temperature is in the range of 1600-1620°C [3].

2.2. Ladle Furnace

Secondary Metallurgy or Ladle Metallurgy as it is commonly used covers all metallurgical processes such as heating of molten steel, deoxidation, desulfurization, composition adjustment, homogenisation, flotation of inclusions and degassing.

Liquid steel is transferred to the ladle. After the centring process of the ladle is completed, the magnetic stirrer and gas blowing system are kept open until the entire process is completed. The ladle must first be deoxygenated. Ca, Mn, Si and Al are added to the ladle for deoxidation. After the addition of Al ingot, titanium alloys are added to the liquid steel [4].

One of the other materials added to the ladle is lime. The purpose of the lime material here is to increase the alkalinity in the ladle to obtain basic slag and to remove the sulphur. The removal of sulphur by the slag reaction is shown below:

$$CaO + S \rightarrow CaS + 1/2\ O_2 \quad (2)$$

The steel that reaches the desired alloy values is taken from the ladle furnace and sent to the vacuum degassing section [4].

2.3. Vacuum Degassing

The degassing process starts with placing the ladle with liquid steel inside the vacuum tank and argon gas is sent during the vacuum process. The ladle pressure under vacuum drops to 0.5 mbar. The mixing process under vacuum conditions is achieved by the [C]+[O] = {CO} reaction starting in the steel. Hydrogen is the most important gas to be removed during the vacuum degassing process. Liquid steel, which contains about 8 ppm of hydrogen, contains 2 ppm of hydrogen at the end of the vacuum. Cleaner, lower carbon steel is obtained after vacuum.

2.4. Continuous Slab Casting

Continuous casting is the process in which the metallurgically optimized liquid steel is continuously solidified into a slab after being passed through a moving mould cavity.

The realization stages of a slab casting are as follows and are shown schematically.

Ladle (liquid steel)→Turret→Tundish→Moulding→Pull-Straightening Unit→Cutting

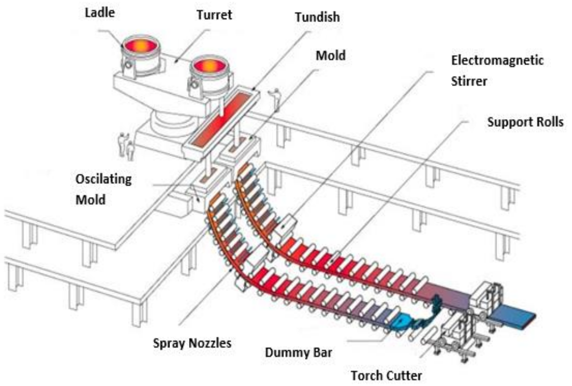

Figure 1. Typical Process Layout; Two-strand Continuous Slab Caster [5].

The liquid steel in the ladle is placed in the turret and poured into the tundish. From the nozzles under the tundish, the liquid steel flows into the mould and is solidified as slab.

The casting machine works with a closed casting system. In this way, liquid steel flows through the refractory tubes and sealing is ensured. The aim here is to cut the contact of the steel with the air and to prevent the formation of inclusions or steel pollution by direct oxidation with O2 in the air.

2.5. Hot Rolling

Slabs are heated up to 1250°C in slab heating furnaces. The slabs coming out of the furnace come to the descale (scale removal). The scale on the slab is cleaned by spraying 210 bar of water. Rolling is done in 5 or 7 passes in the reversibly working quartet mills. The temperature drops from 1250°C to 1140°C. The slab from the roughing mill arrives in the coil box and is rolled. The aim here is to save space and to provide heat homogenization by reducing the surface area. The material that is opened after the coil box and to be taken to the strip mill comes to the crop shear before the strip mill and the uneven coil head and end parts are cut. Afterwards, cleaning is done in secondary descaling. The slab arriving at the strip mill continues to be rolled and its temperature is approximately 960°C. The final thickness of the strip is also given on a 7-foot strip mill.

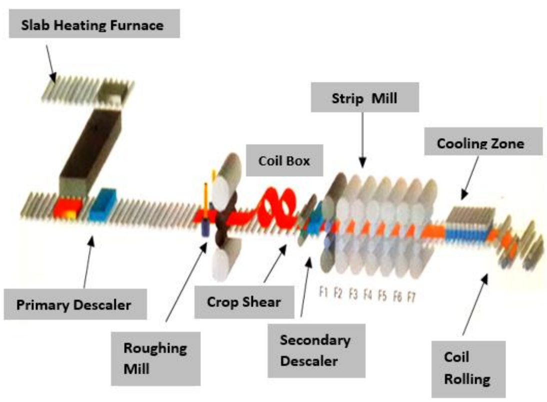

Figure 2. Hot Rolling Process [5].

3. Hot Rolling Parameters

The basic hot rolling parameters that determine the microstructure and mechanical properties of the steel grades to be annealed in the continuous annealing line are as follows:

• Slab Heating Temperature

• Finishing Temperature

• Coiling Temperature

3.1. Slab Heating Temperature

Heating of the slab takes place in the slab furnaces and the dissolution of TiC and NbC precipitates occurs in the furnace. As a result of dissolution, the final hot band texture and grain size are determined. As the slab heating temperature decreases, higher ductility and r values are obtained in IF steels [6].

3.2. Finishing Temperature

In order to obtain a homogeneous microstructure product and to provide the desired mechanical properties, the transformation temperature must be greater than the A3 transformation temperature. In addition to the advantages of high finishing temperature to product quality, it has certain limitations as it causes scale (oxide layer) formation. The best cold rolled and annealed texture is obtained in hot rolled fine grain hot band at 30-80°C above the A3 temperature. As the supply temperature decreases, the grain size, % elongation, and deep drawability values also decrease [6].

3.3. Coiling Temperature

In IF steels, the rolling temperature is preferred high to accelerate ferrite grain growth, promote TiC and NbC formation, and complete precipitation of AlN [5]. As the rolling temperature increases, the % elongation increases, while the yield and tensile strength decreases. With the increase in temperature, the ferrite recrystallization {111} texture is improved and as a result, higher r values are provided [7].

4. Experimental Studies

In the experimental studies, 2 samples with 78-89% reduction ratios were taken from hot rolled Ti-containing IF coils. The rolled sheet sample with a thickness of 2 mm is named A1 and the rolled sheet sample with a thickness of 3 mm is named A2. In these samples, the effects of hot rolling parameters on mechanical properties and crystallographic texture were investigated. Basic chemical analyses of steels are given in Table 1.

Table 1. Chemical analyses of A1 and A2 samples

Sample Number	A1	A2
C	0,002	0,003
Mn	0,107	0,092
Si	0,015	0,012
Ti	0,064	0,061
N	0,007	0,007
P	0,009	0,007
S	0,008	0,004

In order to determine the mechanical properties of the IF quality steel coil, transverse (0°), longitudinal (90°) and diagonal (45°) samples were taken in different directions according to the rolling direction, and tensile tests were carried out with Zwick Z600 device and hardness tests with Zwick ZHU250 device. Samples with different hot rolling reduction ratios of 78% and 89% were polished and grinded for metallographic examinations. The internal structures of the bakelite were etched and examined in the Nikon Eclipse MA200 microscope. Nital solution consisting of 97.5 cc of ethanol and approximately 2.5 cc of nitric acid was used as etching agent in all samples.

5. Results and Discussion

Mechanical tests applied to hot rolled IF steel samples with different deformation rates (78-89%) were investigated. Although only Ti-containing A1 and A2 samples had similar chemical analyses, they showed different % elongation values(ε). The difference here shows that the increase in the reduction ratio causes a higher % elongation in the material. The strain hardening exponent (n) varies between 0.21 and 0.23, and no systematic changes were observed in yield, tensile strength and elongation at rupture.

Table 2. Tensile test results of samples

	Tensile Test Direction	**σ_a MPa**	**$\sigma_ç$ MPa**	**ε (%)**	**n**
A1	0^0	172	324	34,6	0,22
	90^0	183	329	38,7	0,23
	45º	243	321	37,0	0,23
A2	0^0	264	329	41,8	0,21
	90^0	246	329	44,1	0,22
	45º	248	321	47,7	0,23

The hardness test result is given in Table 3. The steel was mild steel (67-450 HB) according to the applied load degree (kp=30) and showed that the samples were IF steel according to the hardness measurement range.

Table 3. Hardness test results.

Sample	A1	A2
HB	92.4	99.0

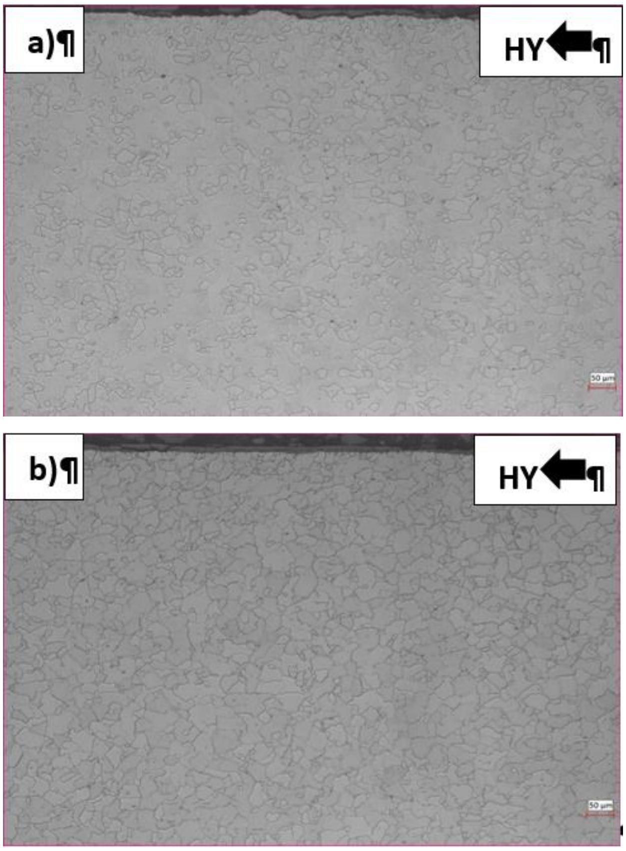

Figure 3. Microstructure view of hot rolled (200x) a) A1 and b) A2 sample

As a result of the microscopic examinations for the 2 mm and 3 mm thick samples taken from hot rolled IF quality steel, the grain size is 9.5 ASTM levels according to the ASTM E112 standard. The grains are arranged along the rolling direction as stated in the literature. The deformation structure is clearly visible. The grains are elongated in the rolling direction. As can be seen from the microstructure images, large ferrite grains are seen in the structure. No second structure was found.

SEM-EDS analyses were performed with the ZEISS Sigma 300 device. The electron beams sent to the sample surfaces by SEM analysis come into contact with the atoms in the sample, and different peak values about their surfaces show the elements and compounds on the surface of the material.

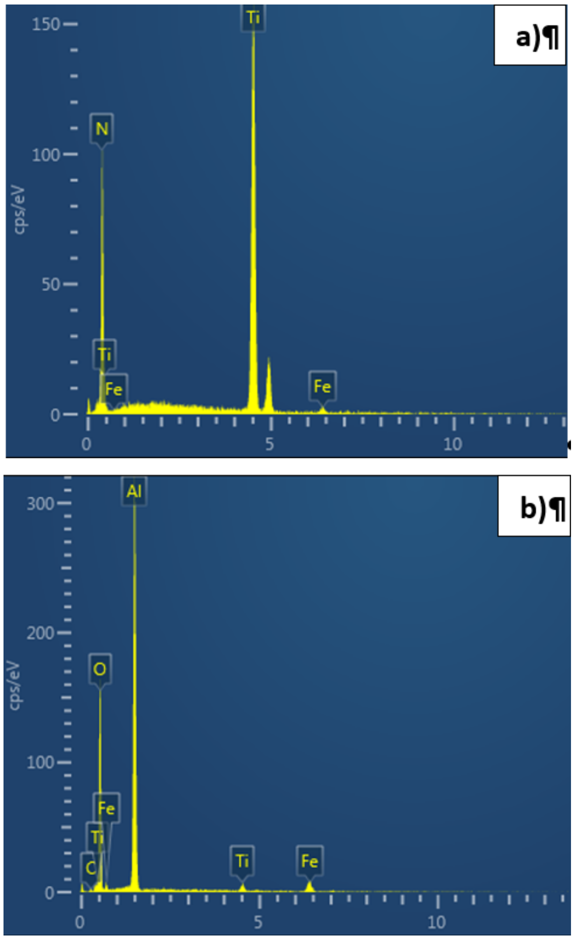

Figure 4. EDS analysis, where amount of Ti: a) increased and b) decreased

When the analysis images made at this point were examined, it was determined that the Ti structure had a maximum peak and N, Fe elements were present. It is seen that precipitates such as Al, oxide is formed with the decrease of Ti amount. It has been observed in this way that the Ti contribution is critical.

6. Conclusion

The aim of this study is to investigate the effect of production process conditions on the chemical and mechanical properties of product and to optimize product quality in IF steels made in EAF, which is used scrap based raw materials. For this purpose, different quality scraps were used with additives such as ferrotitanium. Melted steel was degassed in vacuum, the slab casting process was applied followed by the rolling process. As a result, sheet metal production with optimum width, length and thickness dimensions was achieved. Product characterization was carried out both by chemical analysis, mechanical tests and microstructural examinations. In particular, microstructure investigations have shown that this type of addition is extremely important, since interstitial atoms do not form in this type of titanium-containing steel.

Authors' Contributions

Ali Cem Taşdemir performed experimental execution, writing and editing, while Onuralp Yücel contributed to the study in supervision and editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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