Investigating the Microstructure and Cementite Distribution in Steel Used for Automotive Beams Produced through Compact Strip Processing with Versatile Methods

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Abstract: This study investigated the microstructural characteristics and cementite distribution in hot-rolled strips of automobile beam steels produced via compact strip production (CSP) using advanced microscopy techniques, including scanning electron microscopy (SEM), transmission electron microscopy (TEM), and electrolytic dissolution. The research revealed a distinctive microstructural phenomenon, wherein the cementite lamellae in the as-received hot strips fractured and transformed into dispersed, fine cementite particles throughout the ferritic matrix [1]. This microstructure, formed through coiling at 540°C with a cooling rate of 15Ks-1, significantly impacted mechanical properties. The effects of technological parameters on microstructure formation were thoroughly examined, and the underlying mechanisms driving this unique characteristic were explored in relation to the interaction between dislocations, cementite, and excess carbon concentration.

Keywords: flexible multibody dynamics, impact with friction, momentum balance equations, routh's diagram, poisson's hypothesis

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1. Introduction

The morphology and structure of cementite and pearlite have been extensively studied in the literature, revealing various morphologies of cementite and ferrite under different conditions. A desirable microstructure for refining and strengthening plain carbon steels is a dispersion of fine cementite particles throughout the matrix. However, this microstructure is rarely found in as-received material after rolling, typically requiring specific heat treatments such as solutionization, quenching, tempering, annealing, or aging [2].

Recently, an interesting phenomenon has been observed in some as-received hot strips produced by compact strip production (CSP), an advanced manufacturing technology in the modern iron and steel industry. CSP produces hot strips using a short production line and has distinct differences from conventional processes, particularly in thermal history. This study focuses on two samples of automobile beam steel with different strengths, produced by CSP with varying cooling rates [3]. Notably, the sample with superior mechanical properties exhibits a microstructure characterized by finer cementite particles dispersed throughout the matrix.

Understanding the formation of different microstructures using CSP technology is crucial for industrial production. This research aims to investigate the microstructure and cementite distribution in hot-rolled automobile beam steels produced via CSP, exploring the effects of technological parameters on microstructure formation and the underlying mechanisms driving this phenomenon. By examining the interaction between dislocations, cementite, and excess carbon concentration, this study seeks to provide insights into the optimization of CSP processing conditions for improved mechanical properties [4].

2. Material and Procedure

The automobile beam steel used in this study had a chemical composition as listed in Table 1. Two different compact strip production (CSP) processing conditions were employed, as presented in Table 2. To examine the microstructure, samples were prepared using standard metallographic techniques and etched in 4% nital. A LEO-1450 scanning electron microscope (SEM) was utilized for microstructural analysis.

Element	C	Si	Mn	P	S	Cu	Ni	Cr	Ti
wt.%	0.2	0.3	1.2	0.06	0.004	0.1	0.03	0.03	0.07

Table 1. Chemical composition of an automobile beam steel produced by CSP (wt.%)

Item	1	2
Entry temperature (°C)	1220	1250
Exit temperature (°C)	900	890
Coiling temperature (°C)	680	640
Strip thickness (mm)	7.0	7.5
Average cooling rate (°C/s)	10	15

Table 2. CSP processing conditions

For transmission electron microscopy (TEM) analysis, foils were prepared from the surface region in the rolling plane of two steel samples. Discs of 3mm diameter were ground to a thickness of approximately 0.05-0.08 mm. Each disc was then jet-thinned using a MTP-1A Twin Jet Electropolisher with a solution of 5% perchloric acid in ethanol at -30°C and a voltage of 60-80V. Following jet-thinning, conventional TEM techniques were employed to analyze the microstructure of the steel samples.

The jet-thinning process was carefully controlled to achieve a uniform thickness and to prevent any damage to the samples. The resulting foils were then examined using transmission electron microscopy to reveal the fine details of the microstructure. The TEM analysis provided valuable information on the morphology and distribution of cementite particles, as well as the dislocation structure and grain boundaries.

In addition to SEM and TEM analysis, electrolytic dissolution was also employed to further characterize the microstructure of the steel samples. This technique allowed for the examination of the cementite particles in three dimensions, providing a more comprehensive understanding of their morphology and distribution. By combining the results from SEM, TEM, and electrolytic dissolution, a detailed picture of the microstructure of the automobile beam steel could be obtained.

3. Result

The microstructure of hot strip sample 1, consists of polygonal ferrite and a small amount of pearlite. In contrast, hot strip sample 2 has a microstructure comprising ferrite and a small amount of pearlite that is uniformly distributed in the vicinity of ferrite, with some fraction of granular bainite also present. A notable difference in the shape of pearlite is observed between the two steel samples. Specifically, the cementite lamella in hot strip 1 appears fractured and transformed into a dispersion of fine cementite particles of variable size, which are distributed throughout the ferritic matrix of hot strip 2.

Further examination by TEM reveals feathering in both samples. At high magnification, the TEM micrographs that the cementite lamella in hot strip 1 has started to fracture and transform into discrete particles, forming cementite chains or lamellae fragments along the former lamellae located at the areas of the former pearlite colonies. In contrast, the morphology of cementite in hot strip 2 is irregular, with an inhomogeneous distribution. The reasons for this phenomenon will be discussed in a subsequent section.

A statistical analysis of strength, reveals significant differences between the two hot strip samples. Specifically, hot strip 2 exhibits a yield strength value 100MPa greater than that of hot strip 1, and a tensile strength value 70MPa greater than that of hot strip 1. However, the elongation values for both samples are approximately the same. The differences in strength between the two types of hot strips can be attributed to the dissimilarity in their microstructures.

4. Discussion

The processing parameters, such as cooling rate and coiling temperature, significantly influence the microstructure and dislocation density of the hot strips. The deformation-dilatometry technique revealed that a lower cooling rate results in a lower dislocation density, while a higher cooling rate leads to the formation of bainite and a higher dislocation density.

The influence of cooling rate on microstructure and dislocation density is attributed to the thermal activation of dislocation mobility. The lower cooling rate accelerates the rearrangement and annihilation of dislocations, resulting in a lower dislocation density [5]. In contrast, the higher cooling rate leads to the formation of bainite, which is accompanied by the generation of high-density mobile dislocations.

The coiling temperature also plays a crucial role in determining the dislocation density. A higher coiling temperature results in a lower dislocation density due to the climbing motion of dislocations during the holding time. The dislocation density in the microstructure of I hot strips was observed to be significantly lower than that in the microstructure of 2 hot strips [6].

The interaction between dislocations and carbon atoms is another critical factor that affects the microstructure and mechanical properties of the hot strips. The high dislocation density in hot strip 2 leads to a higher carbon concentration and an increased degree of interaction between carbon and dislocations. This interaction results in the decomposition of pearlite and the dispersion of carbide particles after the coiling process [7].

The dispersed cementite in hot strip 2 has a significant effect on the mechanical properties. The fine distribution of cementite particles throughout the matrix hinders the movement of dislocations and delays microstructural evolution, leading to improved strength after coiling. The formation of uniformly dispersed fine cementite particles in ferrite grains is desirable for a good combination of strength and toughness [8–10].

The strengthening contribution of fine cementite particles to the yield strength will be further investigated in detail. The results of this study provide insights into the optimization of CSP processing conditions for improved mechanical properties.

The effect of dispersed cementite on mechanical properties is attributed to the hindrance of dislocation movement and delay of microstructural evolution. The fine cementite particles distributed throughout the matrix slow down ferrite growth by dragging the migration of grain boundaries, leading to improved strength after coiling.

In contrast to conventional plain carbon steels, where rod-like cementite is segregated in pearlite colonies, the present microstructure produced by CSP exhibits a fine distribution of cementite particles throughout the matrix [2,3]. This unique microstructure is desirable for achieving a good combination of strength and toughness.

The size and quantitative analysis of cementite in the two types of automobile beam steels revealed that the processing conditions, such as cooling rate and coiling temperature, affect the particle size but not the volume fraction of cementite. The experimental data and SEM observations confirmed that the carbon content affects the volume fraction of cementite but not the ferrite grain size.

The strengthening contribution of fine cementite particles to the yield strength will be further investigated in detail. Understanding the relationship between cementite dispersion and mechanical properties is crucial for optimizing CSP processing conditions to produce high-strength steel products [3,9].

Furthermore, the results of this study have significant implications for the development of advanced high-strength steel products. By controlling the processing parameters and microstructure, it is possible to achieve a good balance of strength and toughness, making these steels suitable for various applications, including automotive and construction industries.

5. Conclusion

The study investigates the effect of processing parameters on the microstructure and mechanical properties of hot strips produced by Compact Strip Production (CSP). The results show that the cooling rate and coiling temperature significantly influence the microstructure and dislocation density of the hot strips. A lower cooling rate results in a lower dislocation density, while a higher cooling rate leads to the formation of bainite and a higher dislocation density. The coiling temperature also plays a crucial role in determining the dislocation density, with a higher coiling temperature resulting in a lower dislocation density. It also reveals that the interaction between dislocations and carbon atoms is a critical factor that affects the microstructure and mechanical properties of the hot strips. The high dislocation density in hot strip 2 leads to a higher carbon concentration and an increased degree of interaction between carbon and dislocations, resulting in the decomposition of pearlite and the dispersion of carbide particles after the coiling process. The dispersed cementite in hot strip 2 has a significant effect on the mechanical properties, hindering the movement of dislocations and delaying microstructural evolution, leading to improved strength after coiling. The formation of uniformly dispersed fine cementite particles in ferrite grains is desirable for achieving a good combination of strength and toughness.

The study demonstrates that the processing conditions, such as cooling rate and coiling temperature, affect the particle size but not the volume fraction of cementite. The carbon content affects the volume fraction of cementite but not the ferrite grain size. Understanding the relationship between cementite dispersion and mechanical properties is crucial for optimizing CSP processing conditions to produce high-strength steel products. In summary, the study highlights the importance of processing parameters and microstructure on the mechanical properties of hot strips produced by CSP. The findings provide valuable insights into the optimization of processing conditions to produce high-strength steel products with improved mechanical properties, making them suitable for various applications, including automotive and construction industries.

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