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Product Development of High Strength and Toughness Spring Flat Steel

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Abstract: With the continuous development of mechanical industry, higher requirements are put forward for the comprehensive properties of spring steel. The chemical composition and production process of spring flat steel are designed to meet the requirements of high strength and high toughness of spring flat steel, through the test, the product surface quality and internal quality all meet the national standards, the performance indicators to meet user requirements.

Keywords: spring flat steel; mechanical properties; high strength; high toughness

Introduction

Springs are one of the important components of motor vehicles, used to support the weight of the upper part of the vehicle or provide cushioning. The use environment of spring flat steel is harsh, and its quality directly affects the performance and driving safety of motor vehicles during use. Therefore, high requirements are placed on the strength, fatigue limit, and impact toughness of spring flat steel [1].

At present, the most commonly used production processes are: converter smelting LF refining continuous casting continuous rolling production process, and the output of spring flat steel is gradually increasing [2,3]. The main types of steel used for producing spring flat steel include 60Si2Mn, 50CrVA, SUP9, SUP9A, 51CrV4, 52CrMnA, etc. With the continuous development of the mechanical industry, spring steel is widely used in various transportation tools such as airplanes, railway vehicles, automobiles, tractors, and engineering machinery, which puts forward higher requirements for the comprehensive performance of spring steel. For example, spring flat steel should meet both high strength and high toughness.

Among the steel grades listed in the national standard GB/T 1222-2016 for spring steel, only spring steel with grade 40SiMnVBE can meet all the above requirements and has obtained patent authorization. In addition, the grades that can meet the requirements of Table 1 for tensile strength and yield strength include 60Si2Mn, 60Si2Cr, 56Si2MnCr, 55SiCrV, 60Si2CrV, and 60Si2MnCrV, but their post fracture elongation or cross-sectional elongation cannot meet the requirements; However, the tensile strength and yield strength of the grade that meets the required elongation after fracture (%) cannot meet the requirements. Therefore, to meet the requirements of Table 1, it is necessary to develop a new spring steel grade [4,5].

1 Chemical element analysis and composition design of high-strength and high toughness spring flat steel

1.1 Chemical element analysis of steel

Composition design is the premise and foundation of product development. After consulting relevant materials, the role of the main chemical elements in steel was analyzed. The chemical composition of alloy spring steel has the following characteristics.

(1) To ensure high elastic and fatigue limits, the carbon content of spring steel should be higher than that of quenched and tempered steel. Carbon is the main strengthening element, and it dissolves in steel to form interstitial solid solutions, playing a role in solid solution strengthening. When precipitation of carbides occurs through the interaction with elements forming strong carbides, it plays a

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precipitation strengthening role, with a general content of 0.45% to 0.70%. If the carbon content is too high, the plasticity and toughness of spring steel will decrease, making it prone to brittle fracture and reducing its fatigue resistance [6,7].

(2) Adding Si and Mn as the main elements to improve the hardenability, while also increasing the yield strength ratio, strengthening the ferrite matrix, and improving tempering stability.

(3) Adding Cr, W, and V as auxiliary alloying elements to overcome the shortcomings of Si and Mn steels (such as overheating and graphitization tendency). In addition, the purification of spring steel has a significant impact on fatigue strength, so spring steel is made of high-quality steel or high-grade high-quality steel.

(4) Vanadium, niobium, and titanium strongly hinder the growth of austenite grains and play a role in refining them. On the one hand, they refine the grain size and improve the yield strength of steel, and on the other hand, they improve the tensile strength in the solid solution matrix metal. However, due to the active nature of titanium and its tendency to oxidize, titanium will not be considered for the time being.

(5) The lower the content of harmful elements such as phosphorus and sulfur, the better; The content of residual elements copper and nickel in steel shall not exceed 0.20%.

Based on the above analysis, the strength and toughness of spring flat steel can be improved by adding common alloying elements to the steel.

1.2 Chemical composition design of spring flat steel

The technical solution for high-strength and high toughness spring flat steel is to select the appropriate content of elements such as carbon (C), silicon (Si), manganese (Mn), chromium (Cr), molybdenum (Mo), vanadium (V), niobium (Nb), while reducing the content of harmful elements such as sulfur (S) and phosphorus (P). High strength and high toughness spring flat steel is produced through the production process of converter smelting LF refining continuous casting continuous rolling [8–10]. The chemical composition design of spring flat steel is shown in Table 1.

Table 1 Chemical Composition Requirements for Spring Flat Steel

C	Si	Mn	Cr	V	Mo
0.46～0.54	0.30～0.45	0.85～1.05	0.80～1.00	0.04～0.055	0.10～0.25
Nb	Ni	Cu	P	S	
0.015～0.030	≤0.20	≤0.20	≤0.025	≤0.020	

2 Production test requirements

The production equipment of Baosteel Steel Plant includes a 150 ton converter, a KR desulfurization station, an online argon blowing and wire feeding station, a 150 ton LF refining furnace, and an R10 arc 10 machine 10 strand alloy steel billet continuous casting machine, producing 150 mm2 billets. Adopting a process route: hot metal pretreatment -150t converter -150t LF refining - billet continuous casting (crystallizer electromagnetic stirring+end electromagnetic stirring) - steel rolling.

2.1 Converter smelting

(1) End point control target

[C] ⩾ 0.10%, [P] ⩽ 0.010%, [S] ⩽ 0.020%.

(2) Block slag for steelmaking, strictly control the amount of slag, and ensure that the thickness of the slag layer is ⩽ 100 mm.

(3) The selection of deoxidizer after the furnace includes calcium carbide, aluminum iron, and silicon calcium barium, which can be fine tuned according to the actual situation on site.

(4) Alloy selection: Alloying with silicon manganese alloy, silicon iron, aluminum iron, vanadium iron, chromium iron, molybdenum iron, niobium iron, etc.

2.2 LF refining

The LF refining time shall not be less than 40 minutes, and the white slag refining time shall not be less than 15 minutes. The adjustment of the soft blowing argon gas flow rate shall be based on the slight fluctuation of the steel liquid level, and the soft blowing time must be ensured to be ⩾ 10 minutes, and the sedation time must be more than 5 minutes.

2.3 Continuous castin

(1) The allowable deviation of the cross-sectional size of flat steel should comply with the provisions in Table 2.

Table 2 Permissible Deviation Materials for Cross Section Dimensions of Flat Steel

Width B/mm	Width deviation/mm	Thickness t/mm		
		t≤20	20＜t≤40	40＜t≤60
50＜B≤100	±0.70	±0.20	±0.30	±0.50
		±0.20	±0.30	±0.50
100＜B≤120	±0.80	±0.20	±0.30	±0.50
120＜B≤150	±1.00	±0.20	±0.30	±0.50
Round corners of four cornersr/mm		8±2	8±2	12±2

(2) Bending degree

The bending of flat steel per meter of length should comply with the provisions of Table 3.

Table 3 Bending of Flat Steel per Meter of Length

bending direction	Curvature/mm
Side bending	≤3.0
Flat bending	≤5.0

3 Product result analysis

The specifications produced according to this technical solution are 28 × 90,The mechanical performance test results of 90 spring flat steel are shown in Tables 4-5. The mechanical properties such as tensile strength, yield strength, elongation, and reduction of area all meet the requirements. The surface of the spring flat steel is free of defects such as cracks, folds, scars, and inclusions.

3.1 Chemical composition

Produce 4 batches of steel, with batch numbers 18C01599, 18C03459, 18C03460, and 18C03461 respectively. All chemical compositions meet the design range, and the fluctuation range is narrow, with good control effect.

3.2 Mechanical properties

The results of mechanical performance testing are shown in Table 4.

Table 4 Mechanical properties of spring flat steel

Serial Number	batch number	Rolling specifications	tensile strength (MPa)	yield strength (MPa)	reduction of area%	elongation%
	control requirements		⩾1500	⩾1300	⩾35	⩾8
1	18C01599A-1	28×90	1510	1409	46	9.5
2	18C01599A-2	28×90	1512	1411	47	10.5
3	18C01599B-1	31×90	1519	1416	47	12.5
4	18C01599B-2	31×90	1517	1414	46	11
5	18C03459A	28×90	1522	1422	47	8.5
6	18C03459A	28×90	1517	1418	47	9
7	18C03459B	28×90	1512	1413	46	9
8	18C03459B	28×90	1507	1409	46	9.5
9	18C03460A	31×90	1523	1424	46	12.5
10	18C03460A	31×90	1527	1429	46	12.5
11	18C03461A	31×90	1516	1417	48	11.5
12	18C03461A	31×90	1522	1422	48	12

All inspection indicators such as size and surface quality, low magnification, inclusions, austenite grain size, and decarburization layer meet the national standard of GB/T 1222-2016 for spring steel.

The low magnification structure of spring flat steel generally has a porosity level of 0-0.5, a central porosity level of 0.5-1.0, and no segregation, all of which comply with the requirements of GB/T 1222-2016 national standard for spring steel.

Non metallic inclusions in spring flat steel: classified as fine non-metallic inclusions, Class A inclusions are of grades 1-1.5, Class C inclusions are of grades 0.5-1.0, and Class D inclusions are of grades 0.5-1.0, all of which meet the requirements.

The austenite grain size of spring flat steel is 7.5-8 grade, with a surface hardness of 292-304 HBW and a decarburization depth of 0.84-1.1, all of which meet the requirements.

3.3 Fatigue test

Fatigue life is an important parameter for the ability of spring flat steel to withstand alternating working stress. The GB/T1222 national standard does not have specific requirements for the fatigue life of spring flat steel, but domestic users require a minimum fatigue life of no less than 80000 times; Some factories have initially proposed the goal of a fatigue life of over 100000 times. Conduct fatigue life tests on the newly developed spring flat steel, specification 31 × 90% of the spring flat steel is subjected to stress shot blasting treatment, resulting in fatigue life of 130000 to 150000 times.

4 Conclusion

(1) Process control: All process parameters during steelmaking, continuous casting, and rolling can be strictly executed according to requirements, providing important guarantees for stable product quality. (2) Chemical composition design: Through the analysis of the action of elastic and flat chemical elements, the designed steelmaking internal control chemical composition is reasonable, and the various properties of the product are stable. (3) Surface quality inspection: The surface quality of the flattened spring is good, and all inspection indicators such as low magnification, inclusions, austenite grain size, and decarburization layer of the flattened spring meet the national standard of GB/T 1222-2016, and the internal quality meets the requirements of the national standard. (4) Mechanical performance testing: The mechanical performance indicators such as tensile strength, yield strength, elongation, and cross-sectional shrinkage meet the requirements of national standards. (5) Fatigue life test: The fatigue test results show that the newly developed spring flat steel has a fatigue life of 130000 to 150000 times, which can fully meet the needs of users.

From all the above test results, it can be seen that the spring flat steel developed through hot metal pretreatment -150 t converter -150 t LF refining - billet continuous casting can meet the performance requirements of high strength and high toughness.

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