Study on ferrite content in 0Cr17Ni4Cu4Nb steel

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Abstract. Ferrite phase in 0Cr17Ni4Cu4Nb destroys the homogeneity of microstructure, lowers the plastic toughness of material, accelerates the aging rate of material during creep, and reduces the service life of material. Therefore, it is of great significance to control the ferrite phase content. Chemical composition and hot processing temperature are the main factors affecting 0Cr17Ni4Cu4Nb. In this article, on the basis of determining a reasonable chemical composition, formation of ferrite phase in the hot processing process has been reduced by controlling the forging temperature. Domestically, it is generally believed that the ferrite phase is supposed to be controlled within 10% and it can be controlled within 5% by the adoption of above measures.

1. Introduction

With the development of domestic power construction towards large capacity and high parameters, the demand for blade steel continues to increase, and its market development potential is huge. According to the statistics, the current total steel demand for turbine blade is approximately 66,000 tons per year. With the further development of electric power construction and the increasing demand for special steel in domestic industries, the output of blade steel will continue to increase. Too high ferrite phase content has adverse effects on the performance of blade steel 0Cr17Ni4Cu4Nb. Thus, controlling the formation of ferrite phase is the key to improve the performance of 0Cr17Ni4Cu4Nb.

As with the α-F phase, ferrite phase in carbon steel, which is body-centered cubic structure, is also an important alloy phase consisting of Fe and C, and the ferrite phase in alloy steel contains alloy elements such as Cr and Mo. The ferrite phase is also called high-temperature ferrite since its formation at high temperature, which results in a slight difference in lattice constant from the α-F phase. Compared to the austenite and martensite forming in subsequent non-diffusion phase transformation, content of ferrite formers such as Cr and Mo in the ferrite phase is relatively higher, while the austenite formers like C is relatively lower.

According to formation mechanism, ferrite phase in steel can be divided into equilibrium ferrite and non-equilibrium ferrite. Equilibrium ferrite is determined by chemical composition in the steel, and increase in the content of ferrite formers such as Cr, Mo, V, and Si in the steel promotes the formation of the ferrite phase, which cannot be reduced by heat treatment. Non-equilibrium ferrite forming at a high temperature is a portion that remains in austenite due to a large degree of undercooling, and can be eliminated by subsequent heat treatment. According to its formation timing, ferrite can be divided into ferrite from solidification and thermal processing, which differ in morphology and distribution and have different degree of influence on performance.

There are a lot of formulas and figures to predict the formation of ferrite in steel, but most prediction methods only calculate the formation tendency of ferrite based on the role of some elements.
in its chemical composition, having not taken the technological factors into account. In order to study
the reason for presence of ferrite in blade steel, a method that takes both chemical composition and hot
processing temperature into account is used to predict the formation of ferrite. The formation of ferrite
depends on chemical composition and thermal processing temperature of the steel \([1]\) irrespective of
the effect of cooling rate factors. The ferrite equivalent \(E_{\text{Fe}}\) can be determined from equation (1) by Cr
equivalent \(E_{\text{Cr}}\) and temperature equivalent \(E_{\text{T}}\), ie.

\[
E_{\text{Fe}} = E_{\text{Cr}} + E_{\text{T}} \quad \text{[2]}
\]

2. Factors affecting ferrite formation

Chemical composition obviously affects ferrite content in the steel. The effect of each element on the
formation of ferrite phase can be expressed in terms of chromium equivalent. Table 1 shows the
internal chemical composition of 0Cr17Ni4Cu4Nb. Ferrite formers (Cr, Mo, W, V, Nb, Al, Si) contribute
to the increase of ferrite content, while austenite formers (C, N, Mn, Ni, Cu, Co) inhibit the
formation of ferrite. It is not difficult to envision that as long as ferrite formers content is controlled to
the lower limit within standard composition range, and austenite formers content is controlled to the
upper limit, the ferrite content in steel can be reduced or eliminated as much as possible. According
to chemical composition of steel, the Cr equivalent in steel, \(E_{\text{Cr}}\), can be calculated by formula (2), ie.

\[
E_{\text{Cr}} = C_r - 40c - 2.4Mo - 4Ni + 6Si + 4Mo + 11V - 30N + 1.5W \quad \text{[2]}
\]

Table 1. Chemical composition control of 0Cr17Ni4Cu4Nb (wt%).

|     | C  | Si  | Mn  | S   |
|-----|----|-----|-----|-----|
|     | ≤ 0.055 | ≤ 1.00 | ≤ 0.50 | ≤ 0.025 |
| P   |     |     | Ni  | Cu  |
|     | ≤ 0.030 | 15.00 ~ 16.00 | 3.80 ~ 4.50 | 3.00 ~ 3.70 |
| Al  |     | Ti  | N   | Nb + Ta |
|     | ≤ 0.050 | ≤ 0.050 | ≤ 0.050 | 0.15 ~ 0.35 |

As shown in formula (2), C, N, and V have a great influence on ferrite, followed by Si, Mo, Ni, and
Mn.

It can be seen that if only the influence of the chemical composition on ferrite is considered,
formation of ferrite can be completely avoided by smelting blade steel according to the designed
chemical composition. According to equation (2), ferrite phase forms when \(E_{\text{Cr}}\) is greater than 10%,
which is controlled within 9% in this article.

Ferrite is also called high-temperature ferrite because its formation temperature is higher, which
can be seen from the Fe-C phase diagram. When the ingot is poured, a first-order transformation of
\(L \rightarrow \delta\) occurs and then a peritectic transformation occurs to form \(\gamma\). On the contrary, when material
processing temperature reaches two-phase region between \(\delta\) and \(\gamma\), or \(\delta\) single-phase region, ferrite
nucleates and grows, and the ferrite will remain in the structure if it does not completely transform to
austenite \(\gamma\) when cooled.

Ferrite is formed when temperature is inappropriately (excessively) controlled during the hot
working process and the normalizing heat treatment process of the steel ingot, especially for the long
holding time at high temperature stage. The effect of heating temperature on ferrite can be calculated
by formula (3), ie.

\[
E_{\text{T}} = \frac{[T(\text{°C}) - 1150]}{80} \quad \text{[2]}
\]
Referring to the method for calculating ferrite equivalent $E_{\delta}$ of the turbine blade steel [1], when $E_{\delta} \leq 11.0$ is satisfied, ferrite phase does generally not form. The above formula is used to predict the trend of ferrite formation, where $E_\delta$ and $E_i$ determine $E_{\delta}$ jointly. If $E_\delta$ is 8.5 and $E_i$ is 1.875 when the forging temperature is 1300°C, then $E_{\delta} = 10.375$, which satisfies the condition of $E_{\delta} \leq 11.0$.

The forging temperature of stainless steel and heat-resistant steel is generally below 1180°C [3]. For example, the initial and final forging temperatures of 0Cr13, 1Cr13, 2Cr13 and 3Cr13 are 1150, 850°C, of 1Cr18Ni9T are 1180 and 850°C, and the initial and final forging temperatures of 2Cr3WMoV are 1150 and 800°C, respectively. 0.05% C vertical section of the Fe-C-Cr phase diagram is given in literature [4], as shown in Figure 1. It can be seen that two-phase region of high-temperature ferrite and austenite appears when Cr content is 17% and heating temperature is 1200°C.

3. Measurement of ferrite content
Metallographic method is adopted, that is, the strictest and best field of view was selected by superimposing grid onto image under the metallurgical microscope, and an average of n monitored fields of view was obtained by averaging results of total target numbers or test points divided by the number of grids.

Cross-section of the specimen was polished and then etched with aqueous ferric chloride solution to determine the ferrite content. The ferrite was in shape of a strip under the microscope whose microstructure is shown in Figure 2. The GB/T13305-2008 metallographic detection method standard for $\alpha$ phase area content in austenitic stainless steel was used to comprehensively observe the entire inspection surface and select the heavier view field of ferrite. 5 view fields were selected and averaged for each sample to quantify ferrite content, and the test result is shown in Table 2. It is shown that formation of ferrite can effectively be suppressed by the above control measures, and the ferrite content in single field is less than 5%.

![Figure 1. Vertical sections of phase diagram of 0.05%C in Fe-C-Cr.](image1)

![Figure 2. Ferrite phase morphology of 0Cr17Ni4Cu4Nb steel](image2)
Table 2. 0Cr17Ni4Cu4Nb ferrite phase detection results.

| Furnace ingot No. | Position | Site                | Ferrite (%) |
|-------------------|----------|---------------------|-------------|
| 15121             | riser    | Outer wall          | 4           |
|                   |          | 1/2 radius          | 3           |
|                   |          | center              | 1           |
|                   | tail     | Outer wall          | 3           |
|                   |          | 1/2 radius          | 2           |
|                   |          | center              | 5           |
| 25266             | riser    | Outer wall          | 5           |
|                   |          | 1/2 radius          | 3           |
|                   |          | center              | 4           |
|                   | tail     | Outer wall          | 4           |
|                   |          | 1/2 radius          | 3           |
|                   |          | center              | 4           |
| 25269             | riser    | Outer wall          | 4           |
|                   |          | 1/2 radius          | 5           |
|                   |          | center              | 5           |
|                   | tail     | Outer wall          | 4           |
|                   |          | 1/2 radius          | 4           |
|                   |          | center              | 5           |
| GB/TB732          | ---      | ---                 | ≤10         |

4. Conclusions

(1) In order to investigate the reason why ferrite may appear in blade steel, a method that takes into account both chemical composition and hot processing temperature is used to predict the formation of ferrite. By reducing content of ferrite formers and increasing content of austenite formers, a lower chromium equivalent is obtained and thus ferrite formation is reduced. At the same time, the ferrite content is effectively reduced by appropriately controlling the processing temperature.

(2) Chemical composition plays a decisive role in the formation of ferrite. C, N, V each has a greater influence on ferrite, followed by Si, Mo, Ni, and Mn.

(3) Ferrite is formed when temperature of steel ingot is not properly controlled during heat processing of forging and normalizing heat treatment.

(4) Accuracy and reliability of the test results are ensured by metallographic measurement method using manual point-by-point counting.

References

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