China Steel Technical Report, No. 32, pp.26－29, (2019)

Development of Electrical Steel Grade 25CS1250HF for Electric Vehicle

YEN-TING LIU*, SHIH-TING LIN*, I-CHING HSIAO** and MING-CHIN TSAI**

* Metallurgical Department.
** Iron and Steel Research & Development Department
China Steel Corporation

As the environmental regulations and energy saving issue is increasingly concerned, the requirement for thin gauge ES rises sharply, which is used for traction motors in electric vehicles (EV). CSC has been developing a thin gauge ES since 2008 and successfully developed a supreme 0.25mm product- 25CS1250HF in 2016, supplied to a well-known EV manufacturer for the new generation of EV traction motor. 25CS1250HF belongs to the thin gauge ES, which requires low iron loss at high-frequency, high magnetic flux density, and high tensile strength. To fulfill the requirement, CSC optimized the alloy content to reduce iron loss at high-frequency and raise the tensile strength, and controlled the texture evolution to improve the magnetic flux density. According to the formula of iron loss, the ES product should be made to an optimized grain size to minimize the iron loss. CSC let the grain size of products optimized to control the high frequency iron loss (W10/400) at around 12.30 W/kg by adjusting the annealing temperature. CSC successfully developed 25CS1250HF by the combination of metallurgical technology cumulated over the decades together with new facilities. CSC will continue to make efforts in the development of thin gauge ES, especially for lower iron loss with higher strength so to enhance our market competitiveness and implement better EV design to save the world through sustainable development.

Keyword: 25CS1250HF, Thin Gauge ES, Electric Vehicles

1. INTRODUCTION

The thickness of Electrical Steel (ES) less than 0.30mm is categorized as thin-gauge ES. As the environmental regulations and energy saving issue is increasingly concerned, not only is the ratio of ES applied to new energy saving vehicles and high efficiency motors but also the demand of high grade and thin gauge ES grow significantly.

The technical threshold of thin-gauge ES is extremely high, which is only provided by particular steel mills in the past. CSC started to develop the thin-gauge ES with less than 0.30mm thickness and successfully thinning to 0.20 mm in 2011. In 2014 the new non-grain-oriented ES production line launched to improve CSC's manufacturability for high grade and thin gauge effectively, which created CSC's new era for developing ES product.

CSC has cooperated with an electric vehicle manufacturer for a long time, by suppling 0.35mm ES product. In 2016 the customers propose the thin-gauge and high strength ES requirement for their new model. Based on the EVI concern CSC assisted them to develop the new product 25CS1250HF.

2. THE REQUIREMENT OF PRODUCT APPLICATION

The main application of CSC's ES product 25CS1250HF is the traction motor of electric vehicles (EV), which requires low iron loss at high-frequency, high magnetic flux density, and high tensile strength. The relationship of specific requirement and product application are shown as follows:

2.1 Low iron loss at high-frequency

A motor with high efficiency is necessary to maintain EV cruising endurance. To fulfill the energy saving requirement in high speed mode, the control of high-frequency iron loss for 25CS1250HF is set as W10/400 ≦ 12.5 W/kg. Considering the operating frequency conversion during cruising, CSC also need to control the W15/50 as low as possible.

2.2 High magnetic flux density

High torque is necessary for traction motors to spur operation and reduce the time reaching operating speed during the start-up phase. The copper loss, the main energy loss of motor in start-up phase can be reduced drastically with high magnetic flux density material. The magnetic flux density target is controlled as B50≧1.62 T.

2.3 High strength

A centrifugal force is generated during rotation of the rotor, which is proportional to rotation radius. Under long-term operation the junction part in the rotor would rupture and the motor life would be shortened. By using the high strength ES, the motor life can be extended by avoiding failure of the rotor caused by centrifugal force. The tensile strength target is controlled as YS≧380 MPa.

3. THE DESIGNATION OF 25CS1250HF PRODUCT

The main issues of development of 25CS1250HF are low high-frequency iron loss, high magnetic flux density, and high yield strength. The corresponding analysis was studied from metallurgical aspect as follows:

The total iron loss (W_T) usually separated into 3 parts: hysteresis loss (W_H), eddy current loss (W_E), and anomaly eddy current loss (W_{AE}). The relationship would be as the following[(1)(2)]:

$$W_T = W_H + W_E + W_{AE} \quad \text{(1)}$$

The hysteresis loss (W_H) is proportional to the frequency (f) and hysteresis loss coefficient (K_H), inversely proportional to grain size (Gs^{-1}).

$$W_H = K_H \times Gs^{-1} \times f \cdots \quad \text{(2)}$$

The eddy current loss (W_E) is proportional to the frequency squared (f^2), thickness squared (t^2), eddy current loss coefficient (K_E), and inversely proportional to resistivity (ρ^{-1}).

$$W_E = K_E \times t^2 \times f^2 \times \rho^{-1} \quad \text{(3)}$$

The anomaly eddy current loss (W_{AE}) is related to grain size ($Gs^{1/2}$), frequency ($f^{3/2}$), and resistivity (ρ^{-1}).

$$W_{AE} = K_{AE} \times Gs^{1/2} \times f^{3/2} \times \rho^{-1} \quad \text{(4)}$$

According to the formula (3), reducing the thickness can lower the eddy current loss (W_E), therefore the high speed motor which operates in high frequency tends to use thin gauge ES product to minimize the iron loss.

4. EXPERIMENTAL METHOD

4.1 The composition designation and control of 25CS1250HF

CSC checked the developed high grade ES and confirmed the high-frequency iron loss wasn't low enough. According to the formula (3), the addition of alloy can increase the resistivity (ρ), and let the eddy current loss (W_E) reduce to meet the requirement. Furthermore, the strength of material is proportional to the amount of Silicon and Aluminum, because those elements are solid solution strengthening atomics. In summary, CSC adds more silicon and aluminum into 25CS1250HF to reduce high-frequency iron loss and enhance the strength.

The required composition of 25CS1250HF is not only high silicon and aluminum content but ultra-low impurities. The impurities would interfere with the grain growth during the annealing process so reducing the grain size drastically. According to the formula (2) the hysteresis loss (W_H) will increase significantly. Therefore, it is necessary to keep the impurities at an ultra-low level.

4.2 The parameters for the annealing procedure of 25CS1250HF

The manufacturing procedure of 25CS1250HF is designed as follows: *Steel making → Hot rolling → Cold rolling →* Annealing *& Coating.* The magnetic properties are mainly decided in the annealing and coating procedure.

According to the formula (2)(4) and figure 1, the increase of grain size could reduce the hysteresis loss (W_H) but increase the anomaly eddy current loss (W_{AE}). From the above the ES consists of the optimized grain size to minimize the iron loss.

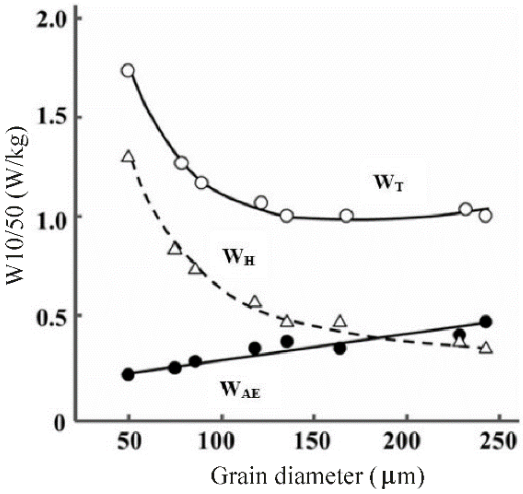

Fig.1. The relationship between iron loss and grain size.[(3)]

The grain size is decided mainly by the annealing temperature in the annealing & coating line (ACL). In order to obtain the optimized annealing temperature, CSC arranged several trials to find out this value.

Furthermore, the iron loss deteriorates if the strain accumulates, so it's necessary to reduce the strain to keep iron loss low.

5. RESULTS AND DISCUSSION

Tables 1 & 2 show the results of magnetic properties of 25CS1250HF, which is already widely accepted by EV manufacturers due to its excellent properties. In order to help customers design motors, CSC also provide the magnetic characteristic curves as follows.

6. CONCLUSIONS

Due to the increasing demand of EV, thin gauge ES can greatly reduce eddy current loss of the motor core and thereby improve the motor efficiency. In 2014 the new non-grain-oriented (NGO) ES production line activated just in time, sending CSC into the new era of developing high alloys and ultra-thin gauge ES products.

CSC has successfully developed the thin gauge ES product 25CS1250HF by combination of metallurgical technology cumulated over the decades together with new facilities, as well as developing ES with customers via EVI.

For the magnetic properties, CSC optimized the alloy design to reduce eddy current loss, and optimizes the annealing parameters. The high frequency iron loss (W10/400) has been controlled at around 12.20, which matches the development goal of (W10/400≦12.50 W/kg).

Table 1 The typical iron loss value of 25CS1250HF.

Iron Loss (W/kg) of 25CS1250HF								
$W_{10/50}$	$W_{15/50}$	$W_{10/60}$	$W_{15/60}$	$W_{15/100}$	$W_{15/200}$	$W_{10/400}$	$W_{5/2000}$	$W_{2/5000}$
0.79	2.01	0.97	2.34	4.46	11.20	12.19	40.76	33.35

Table 2 The typical magnetic flux density value of 25CS1250HF.

Magnetic Flux Density (T) of 25CS1250HF						
B1	B3	B5	B10	B25	B50	B100
1.12	1.34	1.40	1.46	1.55	1.65	1.78

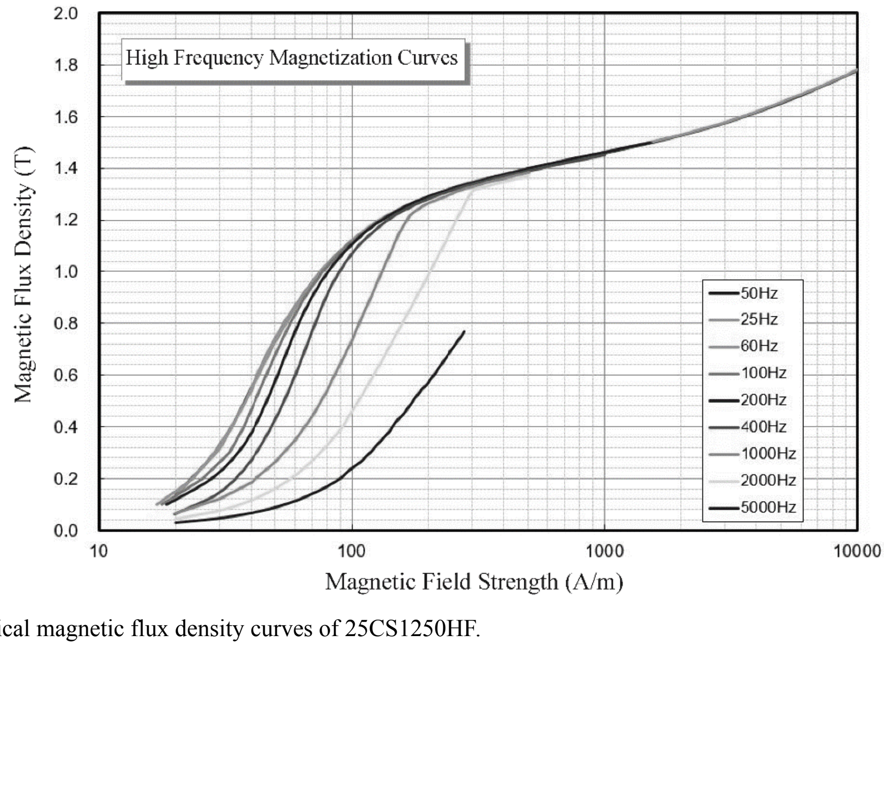

Fig.2. The typical magnetic flux density curves of 25CS1250HF.

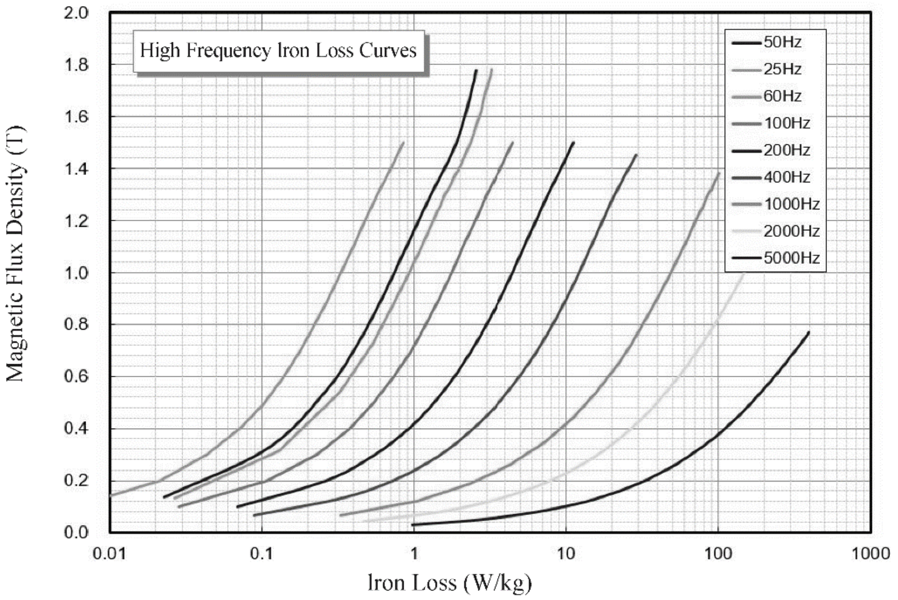

Fig.3. The typical iron loss curves of 25CS1250HF.

At present, many car manufacturers and motor factories have come to CSC to inquire about the thin gauge ES specification. The future demand is estimated to keep growing year by year. Looking forward to the future, CSC will continue to make efforts in the development of thin gauge electrical steel, especially for lower iron loss together with higher strength to enhance our market competitiveness and implement better EV design to better the world of sustainable development.

REFERENCES

1. 蕭一清,黃議興,陳宗榮, "電動車驅動馬達用電磁鋼片開發 Development of Electrical Steels for EV Traction Motors," 鑛冶, vol. 54, no. 2, pp. 47–53, 2010.
2. E. Barbisio, F. Fiorillo, and C. Ragusa, "Predicting loss in magnetic steels under arbitrary induction waveform and with minor hysteresis loops," IEEE Trans. Magn., vol. 40, no. 4 I, pp. 1810–1819, 2004.
3. K. Matsumura and B. Fukuda, "Recent developments of non-oriented electrical steel sheets," IEEE Trans. Magn., vol. 20, no. 5, pp. 1533–1538, 1984.
□