A Study on Analytical Methods of FEM-based Edge Heating System

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This paper focuses on analytical methods of finite element method (FEM)-based edge heating system. The edge heating system plays a role in maintaining the temperature in the hot rolling process of carbon steel. Eddy current are generated in moving carbon steel by Faraday's law of electromagnetic induction. Therefore, there is a need for an accurate electromagnetic field analysis method because the eddy current generated in carbon steel greatly affect the heat distribution in carbon steel. In addition, a thermal analysis method is important to confirm the accurate heat distribution in carbon steel. Therefore, electromagnetic and thermal analyses in the edge heating system become important factors, and ductility analysis was performed for high reliability. Thus, an analytical method for FEM-based edge heating system was established for an analytical approach to the edge heating system.

***Index Terms*—Heating system, Analytical methods, Steel heating, Edge heating system**

I. INTRODUCTION

The steel industry can be regarded as indispensable key industry in all industrial fields such as automotive, machinery, shipbuilding, construction, and civil engineering industries. In the steel industry, final steel products such as hot-rolled and cold-rolled steel sheets and reinforcing steel are created by continuous casting and rolling processes after melting iron ores and iron scraps containing iron to create molten iron and reducing impurities [1-2]. Among them, hot-rolled steel sheets are thin steel sheets created by pressing and stretching sheet iron after heating it formed by processing molten iron at high temperature. The edge heating system, the study subject in this paper, plays a role in maintaining the temperature by heating the edge in the process of heating hot-rolled carbon steel sheets at high temperature. Fig. 1 shows the layout of hot rolling, and the edge heating system performs the role in the highlighted area. Carbon steel moves at 0.5 m/s to 1.5 m/s, and the temperature increases by more than 60 ℃ from approximately 900 ℃ using the edge heating system. Eddy currents are generated in carbon steel by the magnetic flux of the edge heating system when carbon steel moves, and these eddy current are lost. The loss becomes a heat source, and carbon steel is heated to perform the role in the hot rolling process. Currently, however, characteristics analysis of the edge heating system has not been sufficiently studied. Therefore, this study aims to perform coupling analysis by coordinate mapping and to establish an analytical approach to the edge heating system.

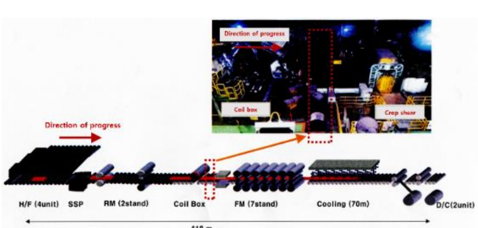

Fig. 1. Hot-rolled layout

II. ELECTROMAGNETIC FIELD ANALYSIS

In order to establish an analytical approach to the edge heating system, it is important to accurately calculate the eddy current loss as a heat source of carbon steel. Therefore, as shown in Fig. 2, there is a need to perform the electromagnetic field analysis after deriving the actual model as an electromagnetic field analysis model. Fig. 3 shows a magnetic flux vector diagram of the edge heating system. A magnetic flux flows in the core and passes through carbon steel between airgap. Eddy current are generated by this magnetic flux as shown in Fig. 4. In addition, larger eddy current generate at the edge than the center of carbon steel. Based on these results, it is estimated that higher heat will generate at the edge.

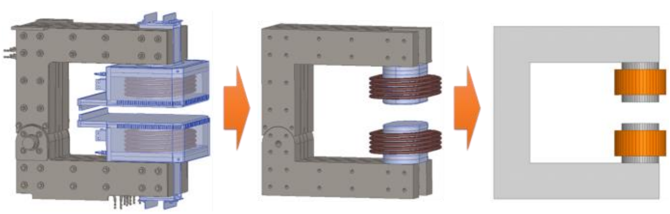

Fig. 2. Model derivation for finite element analysis

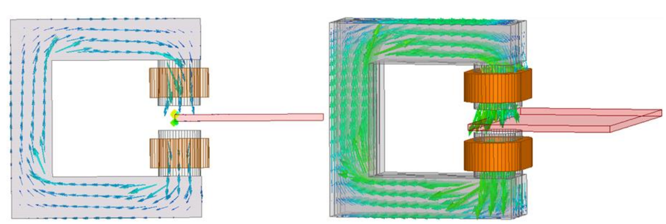

Fig. 3.(a) 2-Dimention (b) 3-Dimention; Model derivation for finite element analysis

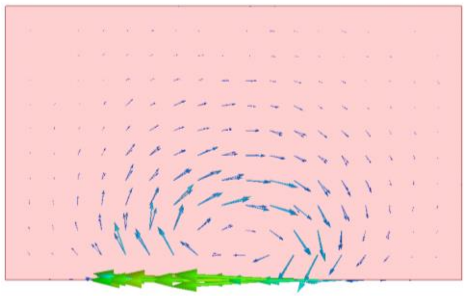

Fig. 4. Eddy current vector diagram of the carbon steel

III. Coupling Analysis by Coordinate Mapping

Fig. 5 shows a conceptual diagram of the Coupling analysis. This study performed Coupling analysis of electromagnetic field and thermal analysis. For more accurate thermal analysis, this study presented coordinate mapping to input eddy current path as a heat source for carbon steel. Coordinate mapping makes it possible to calculate the accurate temperature distribution of carbon steel because the eddy current distribution matches with the heat source distribution for each position of carbon steel in this method. Thus, the analysis results based on the coordinate mapped heat source are shown in Fig. 6. Fig. 4 shows the temperature distribution at the edge at the maximum temperature of approximately 985 ℃ as predicted in Fig. 4. The results satisfy 900 ℃ of the required condition in the edge heating system by more than 60 ℃. Imitating experiments were performed because there is a safety risk around carbon steel to increase the temperature by more than 900 ℃. The imitating experiments were conducted using stainless steel with low thermal conductivity instead of carbon steel. Table 1 shows the thermal conductivity of the materials, and the thermal conductivity of stainless steel accounts for approximately 22% ratio of that of carbon steel. The edge heating system was operated for 10 seconds. Fig. 7 shows the carbon steel temperature distribution in the imitating experiments, and the maximum temperature is 204.6 ℃. Compared with the simulation results in Fig. 6, stainless steel accounts for approximately 21% ratio of carbon steel. The result differs from the ratio of thermal conductivity by approximately 1%, and this study verified a method for coupling analysis based on the experimental results.

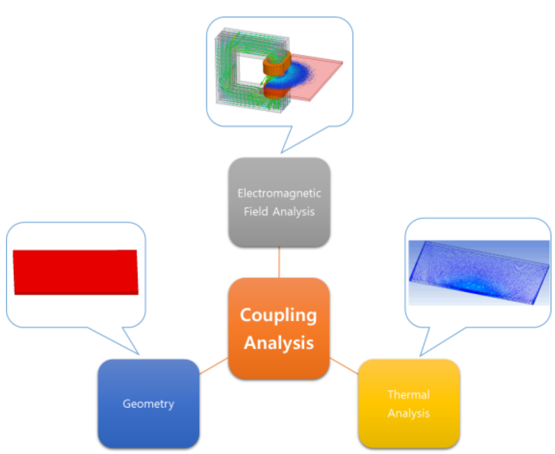

Fig. 5. Conceptual diagram of the coupling analysis

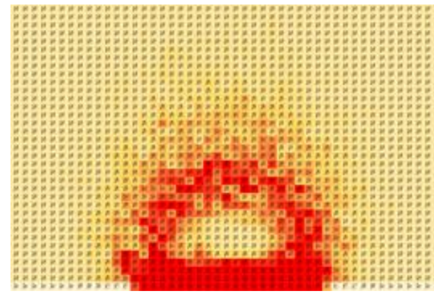

Fig. 6. Temperature distribution of the carbon steel (Simulation)

TABLE I
Thermal conductivity of the material

Material	Thermal conductivity	Unit
Carbon steel	55	W/m·k
Stainless steel	12	W/m·k

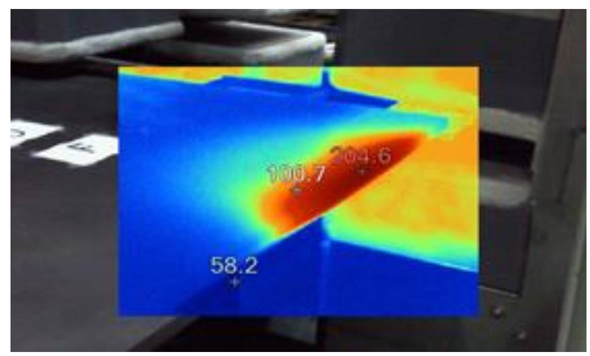

Fig. 7. Temperature distribution of the carbon steel (Experiment)

IV. Conclusion

This paper focuses on analytical methods of finite element method (FEM)-based edge heating system. This study presented imitating analysis method by coordinate mapping to establish an analytical approach to the edge heating system and performed thermal analysis of eddy current path calculated by electromagnetic field analysis based on coordinate mapping. Moreover, this study comparatively analyzed the simulation and experimental results. In conclusion, the edge heating system made it possible to establish analytical techniques by performing coupling analysis by coordinate mapping with an error of approximately 1%.

References

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