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Heat source control intelligent system for heat treatment process

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Abstract

Although precise temperature control in the heat treatment process is a key factor in process reliability, there are many cases where there is no separate heat source control optimization system in the field. To solve this problem, the program monitors the temperature data according to the heat source change through sensor communication in a recursive method based on multiple variables that affect the process, and the target heat source value and the actual heat treatment heat source to match the internal air temperature and material temperature. A control optimization system was constructed. Through this study, the error rate between the target temperature and the atmosphere (material surface) temperature of around 10.7% with the existing heat source control method was improved to an improved result of around 0.1% using a process optimization algorithm and system.

Keywords: *temperature control, heat treatment process, sensor communication, recursive method, heat treatment heat source, process optimization algorithm and system.*

1. INTRODUCTION

Heat treatment technology is a processing technology that expands industrial applicability by treating metal materials using heat [1]. It is an essential process to improve the properties of metals required by industry. It plays an important role in determining the performance of materials used in automobiles, shipbuilding, and electrical and electronic parts. The heat treatment process applies heat to the target metal to deform the material structure and process it to have the desired structure and characteristics according to the processing conditions. Heat treatment technology and process are generally defined as heat treatment technologies and processes. This technology change the characteristics of metal materials such as stiffness, ductility, compactness, and workability by heating and cooling metals through heat treatment according to the purpose of processing.

As a heat treatment process method, standardization (quenching) to make metal materials in a standardized state through heat treatment process, annealing (annealing) to soften to have ductility, conversely, tempering (quenching) to make the organization dense to have rigidity, There is quenching (quenching) to make it hard and strong [2]. The process of changing such a metal material is carried out through heat treatment in which heating and cooling are performed. In terms of process steps, it is divided into a batch process in which heat treatment is carried out in an enclosed space within a heat treatment furnace, and a continuous process in which standardization, annealing, tempering, and quenching are continued using various facilities. In the case of the intermittent process, the heat treatment furnace is composed of a heat source and a refractory material, and the heat source serves as a heater that transfers heat to the material inside the heat treatment furnace, and the

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refractory material serves as a heat preservation and insulation material to preserve this heat.

Heat treatment is performed in various ways such as graphite, high-frequency induction, electron beam (plasma), etc., in addition to the electric furnace using electric resistance. Among them, a thermocouple to measure the temperature of the heat treatment and a temperature controller to control the heat source are used in the electric furnace [3]

In the heat treatment process, the heating temperature value is inevitably different depending on the metal material. Therefore, precise and optimized heat source control is essential for effective process management. In this paper, heat source control optimization using multiple regression-based temperature acceleration algorithm was studied, focusing on the annealing process that increases ductility for 7xxx series aluminum materials with relatively high strength but low ductility. A problem that frequently occurs in the heat treatment process through electric resistance is that when the temperature is raised through electric resistance to a specific temperature value desired by the user, the temperature of the atmosphere inside the electric furnace becomes higher or lower than the target temperature, affecting the properties of the target material. The point is that variables occur [4]. In order to adjust this, it is necessary to measure the temperature change of the material and control the heat source of the heat treatment furnace, but it suffers from difficulties such as lack of management manpower and system introduction cost to operate it in the field [5]. First of all, it is difficult for the experimenter to observe continuously due to the nature of the heat treatment process taking place over a long period of time. In particular, in order to operate the heat treatment process within 48 hours a week, three shifts of manpower are required, but it is difficult to meet at heat treatment sites where there is a severe shortage of workers at the production site. In addition, problems with safety may occur due to the proximity of the experimenter to the heat source. During the heat treatment process, overall safety issues such as burns, respiratory diseases and suffocation due to inert gas always exist. In the situation where the Severe Disaster Punishment Act was recently enacted, while the responsibility of corporate managers for disaster management is growing, professional personnel and systems in charge of various IoT equipment and enterprise-wide resource management to increase on-site safety issues and process efficiency It is being introduced one after another to this heat treatment site [6]. However, the lack of professional process man-power and the need for development by resident development manpower to manage user requirements and efficiency are somewhat difficult for small companies to handle.

Due to the nature of the annealing process, which heats at a relatively low temperature and cools slowly during the heat treatment process to enhance ductility, optimizing process operation through the introduction of new computer analysis-based technology is an important factor in improving process quality [14]. However, there are difficulties in proceeding with appropriate processing due to the complexity of setting methods and limitations of input variables that can be adjusted in current heat treatment furnaces. In particular, heat treatment control according to the characteristics of the material itself exists in tacit knowledge, and there are cases where it is dependent only on the know-how of skilled personnel, so it is often difficult to guarantee uniform quality [7]. In order to overcome this, various attempts have been made to effectively control and predict the heat source for each process site, but a specialized system specialized for the heat treatment process is lacking. In addition, there is a tendency to hesitate to introduce the system due to the budget burden due to the construction cost due to the nature of small and medium-sized companies to directly develop software for these measurements [8].

In particular, for on-site process optimization, an algorithm-based optimization process that can respond to multiple input variables. It is required in the annealing process in which the material surface temperature converges to a target temperature value and then is cooled in air. In case of 7xxx series aluminum, which has relatively high strength, has various input conditions and processing characteristics for each material family, so it is necessary to develop an annealing process condition. It increases ductility and an algorithm corresponding to each material and to manage it as a module.

Therefore, in this paper, we designed a heat source control algorithm optimized for the heat source control of the heat treatment annealing process, implemented a system that can be modularized and applied, and focused on comparing and verifying the optimized performance.

2. Related technology and research

In the heat treatment industry, labor-intensive management is difficult as before, such as the burden of production costs due to the increase in raw material prices, the reduction of training of skilled workers due to avoidance of manufacturing sites, the lack of skilled workers, and the restriction on working hours per week. As a result, more and more sites are actively introducing smart processes using automation systems, unlike in the past, which were operated by skilled workers. In the case of some labor-intensive processes, production was operated using foreign workers, but the introduction of facilities and systems for process automation to improve price and quality competitiveness continues to spread as the influx of foreign workers became difficult due to Corona 19. To support this, a lot of interest and investment are being made in advanced processes such as the Internet of Things, virtual cyber physical systems, and twin manufacturing systems to respond to the global smart manufacturing industry in line with Industry 4.0 through the government-led smart factory support system [9].

In order for small and medium heat treatment companies to introduce automated facilities, it is necessary to expect generation of revenue that can be generated enough to offset maintenance costs incurred due to on-site and system characteristics that can directly affect factory production. Due to the nature of heat treatment companies that deliver to upstream and downstream industries, process changes may occur at the request of customers, so continuous facility investment and development support are required in case of additional requirements [10].

According to the trend of the 4th industrial revolution, multi-variety, small-volume production, requests from companies that produce parts and finished products are increasingly diversified and subdivided. A flexible production system that can flexibly respond to such on-site demand is difficult for domestic companies to easily adopt when considering the size and effectiveness of facility investment. In addition, even after collecting process data and introducing a system that can be properly operated in the field process, the burden of hiring an expert who can supervise the process system still remains [20]. For this reason, most SMEs are hesitant to expand the system due to maintenance and management problems even after introducing the system, or there are situations where it cannot be operated properly due to the absence of field experts and management problems. Therefore, process automation in the heat treatment field should consider not only technological implementation and system introduction, but also systematic management measures to induce and maintain continuous education and voluntary participation of management personnel.

In case of Germany, the beginning of Industry 4.0, large corporations with sufficient investment capacity have achieved remarkable production efficiency through large-scale investment in smart processes, but small and medium-sized enterprises with limited investment capacity often do not feel significant changes before and after introduction. are doing In order to solve these problems, a smart process universal platform that can be commonly applied and utilized in process automation lines has been proposed as a solution. The development and spread of a general-purpose platform that can be commonly used by not only the same industry but also the entire manufacturing company through the accumulated process automation experience to improve productivity can help small and medium-sized enterprises (SMEs). This companies have limited investment conditions compared to large companies, introduce related systems. emerged as a possible solution.

In Korea, which is experiencing the same problems with the introduction of smart processes, an automation platform based on a general-purpose platform is being developed and applied, and even a foreign process automation system platform used by existing large companies can be used by general SMEs as SAAS (Software as a Service). In terms of the operating system, the environmental and technical conditions have improved compared to the past [11].

However, even if it is a universal platform, applications specialized for each manufacturing sector must be separately developed, a cloud system in which data is stored externally must be used, and a previously developed management system must be maintained to maintain the process. This is a reality that is difficult to apply in general [12].

In order to improve these problematic situations, this paper pursues a needs analysis based on user intention rather than focusing on user applications, and analyzes the problems of the current heat treatment and annealing process and then optimizes them and the process that can effectively operate them. The module system was the focus of research.

To this end, the sequential processing of the annealing process is important, but data collection to find elements that require control or careful observation in the process and process model analysis that can be optimized for those areas were needed. The heat source control optimization of the heat treatment annealing process proposed in this paper analyzes the problems of the on-site process and based on this, proposes a model for efficiency improvement such as an optimization algorithm and operating system to derive a system optimized for heat source control in the heat treatment process.

Above all, the heat treatment industry is energy-dependent and is an industrial field in which various researches and field applications for process intelligent are in progress due to the specificity of working conditions. However, with technology and research capabilities at the level of small and medium-sized enterprises, they are experiencing economic limitations to continuously invest in new technology introduction and process application. Therefore, heat treatment engineering software and analysis tools related to this are continuously being researched and developed. The method of applying an optimization model by simulating process variables through modeling software using a double thermodynamics-based database and diffusion coefficient is mainly used. In addition, modeling software for optimal process design data that can simulate process time, etc. through heat treatment time and position and phase data of products receiving heat and determine the hardness accordingly is also widely used in the field.

These analysis programs are mainly being developed by software specialized companies in Germany, France, and the United States, which are manufacturers of heat treatment furnaces. For the convenience of workers and process efficiency, research on automation using robot-related devices continues, and due to the nature of the process requiring long working hours, various methods of remotely managing the process from outside are also being studied.

However, these programs are focused on data analysis and experimental research that simulates the compositional change of the metal subject to heat treatment through the heat treatment process and confirms whether the new process technique is effective or meets the target properties. In addition, although process analysis techniques based on machine learning and deep learning are being introduced recently, an intensive process predictive optimization approach for analytical research for controlling the target temperature value generated in the heat treatment annealing process proposed in this paper is somewhat unsatisfactory [28]. In order to optimize the heat treatment conditions of the target metal in the heat treatment annealing process, it is possible to maximize the process effect by using an algorithm using machine learning based on the heat source, internal atmosphere temperature, and metal monitoring specimen data acquired during the related process. There is a need for an effective process control method through the application of software control.

3. Heat source control optimization theory and implementation

This study predicts the temperature of the heat treatment process retrospectively through changes in three or more input variables, such as the temperature of the material heated by internal heat and the temperature of the internal gas, as well as the temperature in one heat source, and the target temperature value and aluminum material are heated. The goal was to find an optimization method that can minimize the error between the surface temperature values that appear. For the research experiment, multiple regression analysis was performed using multiple input variables such as the temperature of the heat source, the ambient temperature, and the surface temperature to derive a target function including weights. While training the test data, the process of minimizing the error was repeated by calculating the loss value several times for the parameters of the planar regression equation derived as the target function. The mathematical model used, the multiple regression method, is similar to the least squares method calculated with two variables. However, a target function graph having input values composed of multiple variables has the shape of a multi-dimensional plane. By calculating using this determinant, it is possible to obtain parameters for the target function, and through this value, it is possible to predict the temperature change value retrospectively. For error reduction, error correction was carried out based on the gradient descent method to find the minimum value point while tracking and moving the points on the graph when the temperature data change is the continuous movement of points on the graph. After optimizing the function parameters through the derivative equation for the slope of the data, that is, the derivative for each slope of the temperature change at each time, the formula was completed using an approximate formula for the function change with temperature change for a certain period of time to minimize the error rate. . The direction and speed of the temperature data were made into vector data, and the dot product between the previous vector and the current vector was calculated. In this case, the only way to minimize the dot product is when the two vectors are in opposite directions, so based on this, the value of the most optimally moving vector can be calculated and an optimization path with the shortest distance closest to the minimum value can be constructed. Then, based on the previous temperature value and the current temperature change, second-order differential is applied to calculate the acceleration of the temperature change, which is converted into a constant value and applied as a weight of the decision function for the heat source control to determine the temperature increase or decrease temperature control and the amount of temperature change was made to decide.

If the optimization algorithm proposed in this paper is arranged in order, a multiple regression plane equation is derived through process data learning to predict the surface temperature of the material, which is a dependent variable. The return temperature of the internal atmosphere (material surface) temperature was calculated. Next, the temperature change rate by measurement time was calculated through second-order differentiation, and the temperature change acceleration was applied as the weight of the decision function. Subsequently, through multiple regression prediction of the current temperature value through the decision-making logic in the decision function, if the dependent variable material temperature value is determined to be difficult to reach the final temperature value, the temperature is increased according to the weight and predicted to exceed the target temperature Then, the temperature was lowered according to the weight and the calculation was developed in the order of waiting for the appropriate state. In order to implement a heat source control optimization system for the heat treatment annealing process, this paper utilized a temperature controller, an embedded microcontroller unit (MCU), software, and a database-based server-side program based on an electric heat treatment furnace. In order to connect with the temperature controller to control the heating part of the electric heat treatment furnace, an RS485/232 communication device was connected to receive commands through full-duplex communication, execute sequentially in segments, and transmit the results.

The RS485/232 communication device physically connected to the temperature controller of the heat treatment furnace is designed to act as a bridge to control the hardware by connecting to the embedded microcontroller unit. To this end, the microcontroller unit chose the ESP32 embedded board, which has a built-in communication interface and enables transmission and reception through internal functions. In order to develop dedicated programming for system operation, programming was done using a general-purpose IDE that allows easy program debugging. The embedded programming language used was PhPOC, a C language-based embedded script.

Data transmission and reception is designed to utilize an external cloud. As for the data protocol for communication, an asynchronous method using TCP/IP protocol was used. The operating system in which development tools for MCU firmware development were installed was Windows 10 or higher, and Visual Studio was used as a tool for firmware debugging.

Server-side programming utilized a cloud service in a Linux environment. As for the web application program, front-end and server-side programs were developed using node JS and web programming language (PHP 8.x). The database used MariaDB, which has a relatively free license, and HeidiSQL was used as the database management system (DBMS). Microsoft's Visual Studio was used as the integrated development environment (IDE).

Programming for the user screen was developed using the C# language that can be executed on multiple operating systems. The system environment to be implemented executes the command after determining the operating conditions in the operator software where the user can input commands, and the internal program performs multiple regression analysis based on the input variables such as heating part temperature, ambient temperature, material temperature, and time shift values. It was necessary to construct an optimized temperature control algorithm using the second derivative and design it so that it could be applied to the actual process. Therefore, a management system that can be applied to the process by process module unit was implemented so that it can be flexibly applied to the system whenever a new command or sensor is added. In particular, in terms of input variables, the objective function and weight parameters are defined through machine learning that can infer processing results according to changes in the heat treatment process, characteristics of 7xxx aluminum metal materials, differences in process time, etc. After receiving feedback and storing it in an external cloud server, it was designed to be reinforced learning based on this data. Through this, a cyclical program structure that can perform optimization process operation and machine learning at the same time was applied. The flow chart of the optimized heat source control system is shown in Figure 1.

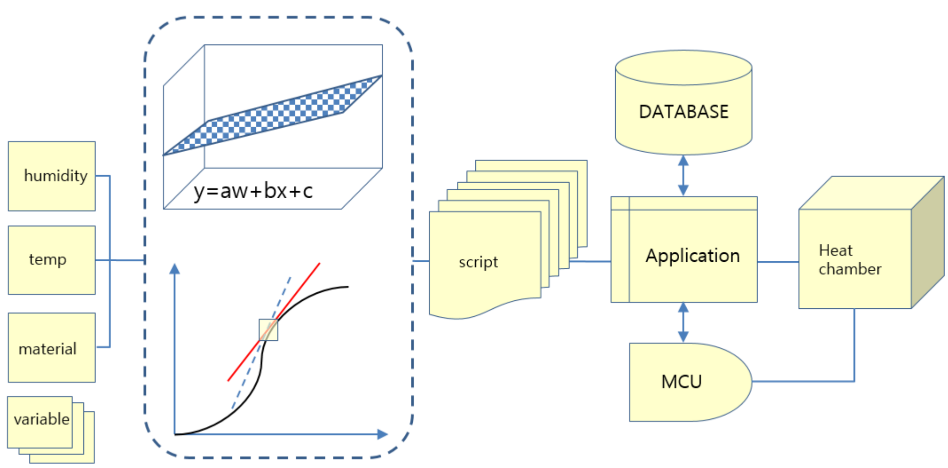

Figure 1. The flow chart of the optimized heat source control system

The embedded MCU connected to the temperature controller of the heat treatment furnace utilized the PHPOC board. It provides modules to create various network protocols and security packets, and has a built-in programmable system using PHPOC language similar to C language. In particular, since server-side programs with web application functions are possible and HTTP/S security networks can be used, it has the advantage of being able to safely transmit and manage the contents communicated with the controller.

In addition, it is a model suitable for precisely analyzing the analog signal of a sensor based on a resolution of 4 bytes (4096 bits). By extending ADC and GPIO ports, it is connected to a board capable of serial communication to control temperature sensors, power consumption, displays, and electric relays. etc. to support. The universal asynchronous transmit/receive (UART) communication used in this paper has a structure capable of RS232/422/485, but under the condition of communicating with a controller with an

RS232 conversion chip, it is managed with a voltage of 3.3v to 5v based on RS232 for monitoring and command control. For the software system, an application program using a C#-based language was developed and implemented to remotely control the heat treatment furnace controller. The application program was developed to process an asynchronous data stream in response to intermittently occurring communication events. In order to communicate serially with the temperature controller built into the heat treatment furnace, hex data values were structured according to the Pc-link protocol specified by the manufacturer so that command and response packets could be transmitted and received. Transmitting and receiving data is configured to store, manage, and respond to data through a server-side program connected to the database. Because a server-side program running on a web server was used, a Rest-Full type program capable of asynchronous web socket communication was developed and utilized.

However, in this paper, the Post method was adopted for experimental implementation, and separate encryption or certificate-based HTTPS protocol was not used. If additional security authentication function is required, it is designed to apply encryption and security by using security authentication module. The received sensor information such as the set temperature of the heat treatment furnace, internal temperature, and electrical output status was configured to be stored in the database in the cloud server through communication with the middleware application program. The database used was open-source MariaDB. Based on the GPL v2 license, we selected a database that is excellent in performance and can be freely distributed in terms of maintenance. Also, the program was designed to set and monitor the values applied to the database. Since the heat treatment controller processes in units of segments, each segment is divided and configured so that data can be transmitted and received. The client software developed for monitoring based on the heat treatment furnace sensor data for this paper is shown in Figure 2.

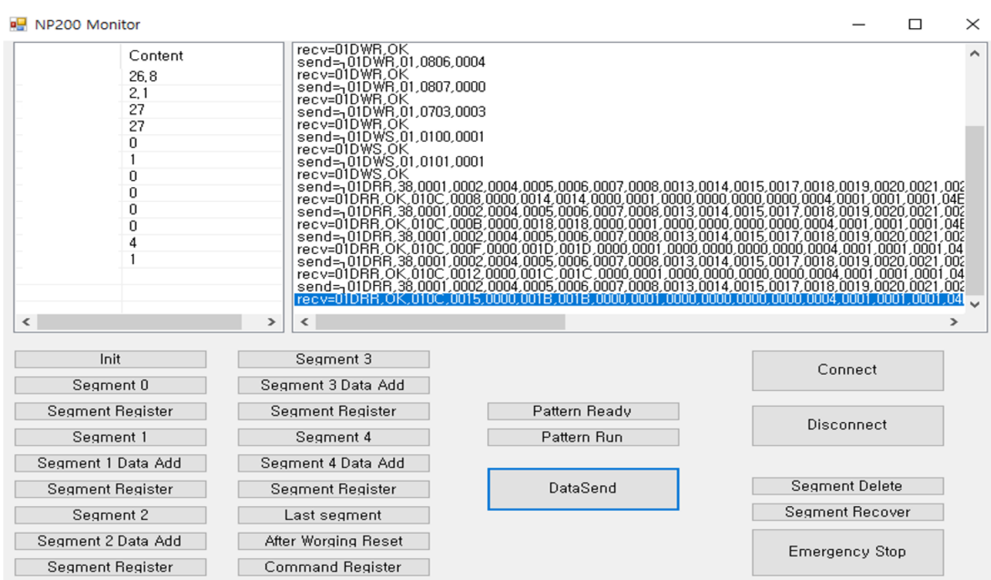

Figure 2. The client software developed for monitoring

4. verification

Regarding the heat treatment heat source control process, the existing method had limitations that could not be applied other than the predefined control method centering on the linear heat source rise. However, the optimization system in this paper is designed to apply the most optimized process according to the situation by applying various heat source controls according to the management variables for each heat treatment annealing process. In accordance with the addition of various input variables, it is possible to control the temperature change in real time using the parameters derived from the gradient descent algorithm and the multiple regression plane equation, allowing precise control of the heat source, which was impossible in the existing method. In general, in order to apply a partial differential-based optimization algorithm that requires high-speed operation, a high-speed GPU and CPU configured in parallel must be connected to an individual heat treatment machine. However, the proposed system was able to easily perform machine learning without purchasing expensive equipment by applying a parallel thread process in batches using an artificial intelligence cloud-based calculation server. In addition, based on central processing such as the process module system, it is designed to allow sufficient system operation through internal edge computing even if external cloud utilization is impossible. Existing equipment was operated in an inefficient structure such that log data was stored in a PLC memory device, moved to an individually connected PC, monitored, and calculated using Excel. However, the optimized heat source control program is designed to enable easy process analysis by configuring a process that provides analysis automation for the current processing process while recording and monitoring real-time process data and predicted data together in a cloud database. In particular, since the input conditions are different for each heat treatment process for each material, and the values of the learning conditions and weight parameters are also different, we developed a system that can remember the learned conditions and apply them again to suit the conditions in the cloud server. Through this preprocessing, complex calculations through cloud resources were processed at low cost, and the derived parameters were transmitted to optimize heat source control.

Even if the temperature value of the heat source control controller reaches the target value by heat treatment, if the internal temperature of the heat treatment is processed at a higher or lower temperature than this, it may cause a defective rate of alloy materials such as specimens undergoing heat treatment. In order to check the process problems of the existing heat treatment furnace, the temperature of the heat source before and after application of the system to the aluminum 7xxx annealing process, the internal temperature of the heat treatment, and the material surface temperature were recorded in real time in the database. As the process time increases, the power energy consumed in heat treatment is converted into heat, and it is impossible to compare internal material temperature change data before and after application of the system. experiment was conducted. As a result of analyzing the process data for the existing control method by applying this process scenario to an electric heat treatment furnace with a maximum power of 1,900W (current 8.6A, voltage 220V) and a temperature resolution of 0.1°C, the heat source target temperature of 120 degrees It was observed that an error rate of 10.5% compared to the target temperature occurred at 107.4 ° C, which is 12.6 degrees lower than the internal ambient temperature (material surface) temperature. Figure 3 shows the temperature change inside the heat treatment measured by the existing control method.

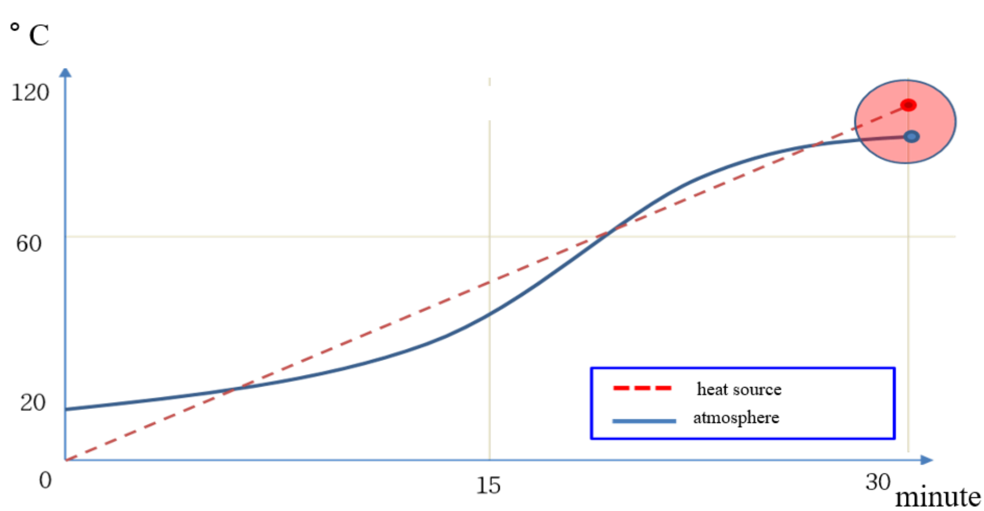

Figure 3. the temperature change before the optimization control method

Since the main variable affecting the material itself during the heat treatment process is temperature, the actual temperature inside the heat treatment furnace must converge to the planned target temperature value within the process time in order to stabilize the material structure. However, one of the important causes of such an error in the existing heat treatment method is that the heating part of the heat treatment furnace increases linearly from the basic temperature of 0 degrees, and the heat treatment that is dependently affected by this increases the temperature of the internal atmosphere or the surface temperature of the material. It was a situation that occurred because there was no feedback process of temperature change according to measurement. In other words, it was a structure inevitably having mechanical limitations in precisely controlling the temperature of the target metal material by proceeding with heating based on the ambient temperature of the heat source heating part rather than the temperature of the object to be heated as a target. In order to solve this problem, we came to the conclusion that the process treatment, including the temperature change of the metal material to be processed, must be optimized. Table 2 shows Compare performance before and after optimization for heat treatment equipment.

Table 1. Compare performance before and after optimization

Division	Setting	Result	Error rate
before	120° C	107.4° C	10.5%
after	120° C	119.8° C	0.1%

Through this, this system monitors the internal atmosphere of the heat treatment furnace during the annealing process of the heat treatment furnace, and the program autonomously controls the temperature of the heating part so that the material surface temperature can finally reach the target temperature value of the annealing process. The sequence of the entire algorithm first raises the temperature to a value below the target temperature value, and when the temperature of the atmosphere inside the heat treatment furnace (material surface temperature) approaches the target temperature, the temperature is raised in stages to minimize the difference between the temperature of the material and atmosphere and the heat source temperature. The heat source was controlled by the method. To this end, it had to be operated to minimize the gap between the heat source and the temperature of the atmosphere inside the heat treatment furnace (material surface temperature) while adjusting the output of the heat source of the heating part. Using the optimization plane equation trained through existing multiple regression machine learning, the predicted value is calculated according to the temperature of the current dependent variable, the heating material, and the input variables, the heat source and ambient temperature, and the difference with the actual material temperature is calculated to exceed the error rate range. In this case, the temperature control method was decided. Through this, if the current temperature change rate is expected to be below the target temperature value when the target time is reached, heating is performed in proportion to the temperature acceleration, and an algorithm is applied so that the temperature can be lowered in the same way if it is predicted to exceed the target temperature value.

Heat source value based on regression plane equation $y = aw + bx + c$ using surface temperature and input variables as dependent variables because there is a mutual difference between the surface temperature of 7xxx series aluminum subject to heat treatment annealing process, the temperature of the atmosphere of the heat treatment furnace, and the temperature of the heat source , the temperature acceleration based on multiple regression analysis devised in this paper was applied to optimize the control of the heat source while monitoring the internal temperature of the heat treatment furnace and the surface temperature of the material. To compare with the existing treatment method, the aluminum heat treatment annealing process was conducted for 30 minutes at 120 degrees Celsius for the same conditions and materials, and the treatment results were recorded. Since the change rate of temperature prediction can be instantaneously estimated according to the increase in the mechanical output of the heat treatment furnace during the experiment, the monitored temperature data is stored in the array memory, and the middle value is obtained after erasing the maximum and minimum values among the data generated during the measurement time. A method of calculating and predicting was used. In addition, the autonomous temperature change value of the software for optimizing the internal temperature of the heat treatment was recorded in the database through sensor communication. Table

2 shows the method of calculation and predicting.

Table 2. method of calculating and predicting

```
import pandas as pd
df = pd.read_csv("data.csv")
fdf = df[['Heat', 'Atmosphere', 'Target']]
fdf.head()
#Multiple regression training, train set 30%, test set 70%
from sklearn.model_selection import train_test_split
X_traindata, X_testdata, Y_traindata, Y_testdata = train_test_split(fdf.drop('Target', axis=1),
fdf['Target'], test_size=0.3, random_state=1636)
# Actual Prediction with Multiple Regression
from sklearn.linear_model import LinearRegression
datamodel = LinearRegression()
datamodel.fit(X_traindata, Y_traindata)
datamodel.score(X_traindata, Y_traindata)
# out : 0.7141131662957088, Correlation of the model is 0<R<1 in the fit range
import statsmodels.api as sm
X_train2data = sm.add_constant(X_traindata)
datamodel2 = sm.OLS(Y_traindata, X_train2data)
result = datamodel2.fit()
result.summary()
```

	coef	std err	t	P>|t|	[0.025	0.975]
const	33.8537	1.839	18.411	0.000	30.232	37.475
a	0.2484	0.076	3.259	0.001	0.098	0.399
b	0.3797	0.079	4.833	0.000	0.225	0.534

```
# y= aw + bx + c
# y: predicted material surface temperature (°C), w: heat source temperature (°C), x: heat source
ambient temperature (°C)
# y = 0.2484w + 0.3797x + 33.8537 (a: 0.2484, b: 0.3797, c: 33.8537)
# y = 0.2484*120°C + 0.3797*120°C + 33.8537 = 109.2°C
# Prediction rate = 107.4°C (measured atmosphere (material surface) temperature) / y = 98.3%
```

As a result of analyzing the experimental data using the original control optimization system, the atmosphere (material surface) temperature of the heat treatment, which was 10.5% lower than the target temperature in the existing heat treatment method, applied the optimization algorithm and proceeded with the annealing process under the same conditions. Compared to the process temperature of 120 °C, the internal atmosphere (material surface) temperature of the heat treatment furnace reached 119.8 °C, and the improvement effect compared to the existing method could be verified. Figure 4-6 shows the temperature change of the internal atmosphere (material surface) after the optimization control method is applied.

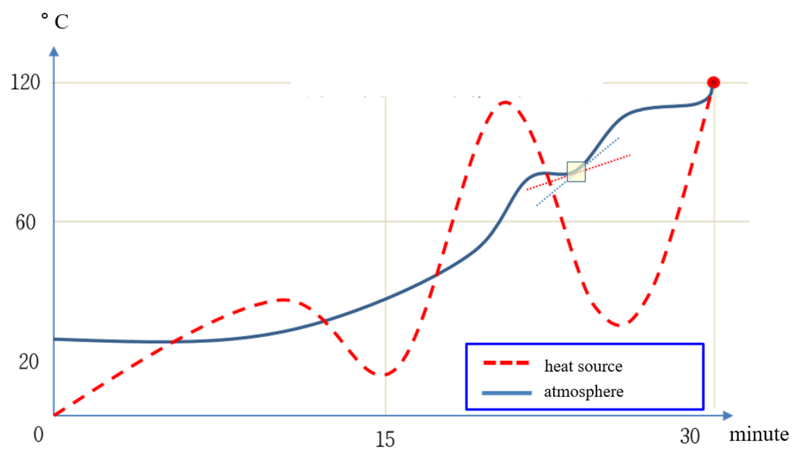

Figure 4. the temperature change after the optimization control method

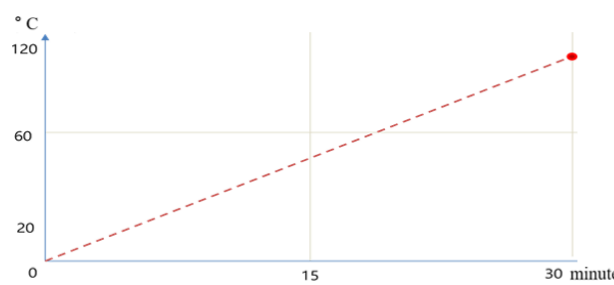

Figure 5. mechanical linear temperature raising method

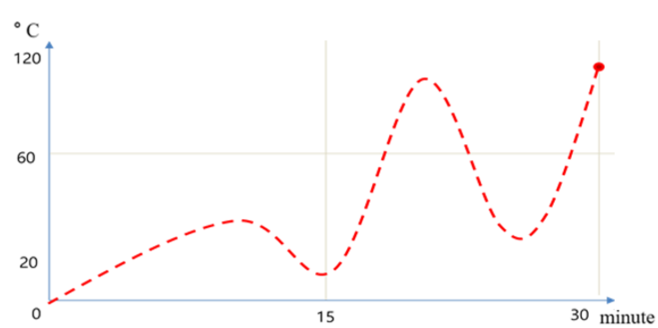

Figure 6. optimized temperature raising method

As shown in the final experimental results, the temperature optimization method using the multiple regression-based temperature acceleration algorithm proposed in this paper does not fall below or exceed the target temperature value within the heat treatment application time compared to the existing mechanical linear temperature raising method, and does not reach the target final temperature value. It shows the result reaching around 0.1% error rate. However, it can be seen that the heating condition frequently rises and falls according to the control of the internal temperature output, so it seems that it is necessary to consider using the existing manual method depending on the material that is sensitive to these changes. However, in general, if the internal temperature value is higher than the melting point of the material, the material itself may undergo a phase change, and if it is low, the heat treatment of the material itself does not work properly. It is considered useful.

5. Conclusion and Future Challenges

Among the process technologies of the root industry, the heat treatment process technology has various field requirements such as long working hours, lack of professional manpower, reduced defect rate, and worker safety management. In particular, for the reliability of the final product, an optimized process management system that considers efficient treatment of heat sources through monitoring of the internal conditions of heat treatment is required. In this paper, after applying an algorithm using temperature acceleration and multiple regression analysis on temperature change of heat treatment equipment, heat treatment temperature control optimization was carried out through a system that applied this to each process module. Machine learning is performed based on multiple regression analysis on the correlation between dependent variables and input variables for the heat treatment annealing process, and by optimizing heat source control through the objective function and parameters derived through this, the limitations of manual control according to the existing mechanical control are improved. The system was implemented to enable precise control. In particular, since time and temperature application scenarios are different for each material in the annealing process to increase ductility targeting 7xxx series aluminum materials with relatively high strength but low ductility, multiple environmental variables affecting each material are set as input variables and the surface of the final material A method of calculating the optimal parameter by setting temperature as a dependent variable was used. The multi-regression equation constructed in this way is substituted into the actual process, and the temperature acceleration is obtained by differentiating the difference between the current material temperature and the heat source temperature.) was optimized to converge to the set target process temperature. In this study, since the optimal power consumption compared to the process time was also assumed as an optimization condition, the heat source was controlled based on the annealing process scenario in which the heat treatment furnace was heated to a final temperature of 120°C for 30 minutes, the minimum process time, and then cooled in air. A comparison experiment was conducted on the efficiency. As a result of the related experiment, the error rate between the target temperature of the heat source and the actual metal surface temperature according to the linear heating method dependent on the internal controller of the existing heat treatment furnace was around 10.5%, but the process improvement through the heat source control optimization method proposed in this paper As a result, it was possible to get an optimized heat treatment process efficiency with an error rate of around 0.1%.

In the existing heat treatment industrial process site, the existing machine-dependent management system had limitations such as server shutdown or process flow interference when adding new IoT equipment or changing processing methods. However, since the purpose of this system was to propose an optimization method for the heat treatment process support system, it was designed to enhance scalability and flexibility within the process system as well as heat source control through an optimization algorithm. Through this, the process module operating system proposed in this paper was able to expand operational flexibility in preparation for the existing process operation by applying the script module in real time when adding various IoT and sensors. In terms of security, not only each module, but also security elements for process data management in the production site were strengthened through encryption of transmission data. In particular, by processing individual processes after compiling the process module through the preprocessing process, as the number of process requests increased, the processing speed was also improved by 15% based on 1,000 times compared to the existing method.

Through the utilization of the research results, it was possible to construct a process optimization model applicable to the domestic heat treatment process site, and to obtain the effect of expanding the process application field by applying the basic system that can be optimized and operated at the heat treatment process site. In particular, by using this study, it was possible to verify the usefulness of the process system grafted with NEW IT technology to the heat treatment process of the root industry. In addition, through these results, the proposed optimization method can be applied to various processes such as standardization (quenching), annealing (annealing), tempering (tempering), and quenching (quenching), which are heat treatment processes that play the most important role in changing metal properties. A basic system model could be presented. Above all, in this paper, by providing an annealing process environment optimized for ductility change of 7xxx series aluminum alloy through optimization of temperature change according to heat source control in heat treatment furnace, it was effective in preparing a system foundation that can affect material heat treatment performance improvement.

As a future plan, various input variables such as power consumption, pressure, atmospheric gas composition, etc., which affect the overall heat treatment, are also planned to be further machine-learned through multiple regression. In addition, I think that the remaining task is to change the network structure and demonstrate it at the process site so that the optimization system of this paper can be extended to protocols frequently used in the Internet of Things such as XMPP, COAP, and MQTT in the future. In particular, it is considered a meaningful research direction to develop an artificial intelligence system optimized for heat treatment process management by expanding the algorithm of this study to create a database of process modules optimized for each processed metal material.

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