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OPTIMIZATION OF PROCESSING PARAMETERS FOR BEAM BLANK CONTINUOUS CASTING USING MOGA COMBINED WITH FEM

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Abstract: In this paper, a new optimization program is developed to search out the optimum processing parameters for beam blank continuous casting. The parameters optimizing method is set up combined the multi-objective genetic algorithms (based on MATLAB) with finite element method (based on ANSYS). The finite element method is used to calculate the thermo-mechanical process for beam blank continuous casting. The multi-objective genetic algorithm is used to search out the optimum processing parameters for beam blank continuous casting. Those optimum parameters can meet all specified requirements but with a minimum expense of the operational and the design constraints and can make it possible to run the caster at its maximum productivity, minimum cost and to cast defect free products. Now, online verifying of this optimization project has been put in practice, which can prove that it is very helpful to control the real production. Compared with the zero order method, the result of this optimizing method is better. This developed optimizing method, taking full advantage of the feature of FEM that computes precisely and the feature of MOGA that search the optimal solution globally and rapidly, provides a method for solving the complex and large engineering problem, especially to the multi-objective optimizing problems.

1. INTRODUCTION

The use of optimization strategies can be seen as a useful tool in the search of operational parameters that maximize or minimize any aspect of the dynamic process. In most of engineering optimization projects, there are multiple objectives and many constraints, which are named as multi-objective optimization (MOP). Among these objectives or constraints, moreover, there have mutual relevancy or interfere. Multiple-objective genetic algorithms (MOGA) is a new kind of optimizing design method to deal with multiple objectives projects with genetic algorithms. MOGA not only can handle large problems, not affected by problems of linear, continuity, differentiability, multimodal, etc., but also can search out the best global solution.

In this paper, an optimization program is developed to search out the optimum processing parameters for beam blank continuous casting. The parameters optimizing method is set up combined MOGA with finite element method (FEM). Those optimum parameters can meet all specified requirements but with a minimum expense of the operational and the design constraints and can make it possible to run the caster at its maximum productivity, minimum cost and to cast defect free products. The method combined FEM with MOGA, taking full advantage of the feature of FEM that computes precisely and the feature of MOGA that

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search the optimal solution globally and rapidly, can play important role in the engineering applications.

2. OPTIMIZING METHOD COMBINED MOGA WITH FEM

Based on the ANSYS software, the finite element method is used to calculate the thermo-mechanical process for beam blank continuous casting in this paper. The multi-objective genetic algorithm, based on MATLAB software, is used to search out the optimum processing parameters for beam blank continuous casting.

In the procedure combined MOGA with FEM, it is key that MOGA procedure uses the FEM procedure and realizes the data transmission between the two kinds of procedures.

APDL stands for ANSYS Parametric Design Language, a scripting language that can be used to automate common tasks, or even build the model in terms of parameters (variables). For the system enclosed by APDL, it is required that the operators input the parameters for preprocessing, then, automatic solution will run. Therefore, in this paper, parameters model is set up and the common tasks are written by APDL, making up the text file and model setting up, meshing, loading, solving and post processing automatically.

In the optimizing process, takes the design variables as the independent variables of the individuals of MOGA, transmitting them to the text file written in APDL. The solution results are obtained from the ANSYS program are looked as the individual objective values of MOGA, thus the datum transmission is achieved. In order to combine MOGA with FEM, the MATLAB program must automatically use the ANSYS program. ANSYS 5.7 provides a kind of batch mode that is as following: “ansys57-b-p ansys_product_feature-i input_file -o output_file” where the input_file is the name of the input file, output_file is the name of the output file. The explanation of the format can be found in ‘Interactive Versus Batch Mode’ in the ANSYS help file. ‘ansys_product_feature’ is the ANSYS product feature code. During the MATLAB program applying the ANSYS program, it is necessary that the judge sentence should be added to make certain if the ANSYS program finishes or not. The applying method is shown as following:

```
void main()
{ int result;
  printf(“Solving...”);
  result=system(“d:/ANSYS57/BIN/INTEL/
  ANSYS57 -b -p ansys_product_feature-i
  input_file -o output_file”);
printf(“Solution finished...”); }
```

3. PROCESSORS FOR MOGA COMBINED WITH FEM

The processors for MOGA combined with FEM are as following:

Step 1: Initialization. Gives the number of the population, crossover probability, mutation probability, and evolution generation etc and then produces the initial generation.

Step 2: Computing the fitness value. It is necessary to change the fitness to obtain the fitness values of the individuals.

Step 3: Selection. Uses the usual selection operator, such as Monte Carlo and combined with the elitist model.

Step 4: Crossover operator. From the selected population, the two individuals are chosen as for the parent generation. The linear crossover operation is used to produce children generation. For each two individuals whose hamming distance is big enough while the objective values are nearly equal, one-point crossover, two-point crossover and multi-point crossover and uniform crossover are executed, from these new individuals choose the two better individuals as the parent individuals.

$$\left\| X_i - X_j \right\| = \sqrt{\sum_{k=1}^{p} \left(x_{ik} - x_{jk} \right)^2}, \quad i = 1, 2, \ldots n-1;\ j = 1, 2, \ldots n, \tag{1}$$

where p is the dimensions number of the individual X.

Step 5: Mutation. According to certain probability, the mutation operation is executed to create new generation.

Step 6: Terminated condition. If the planed gross generation is attained or through M iterative searching, the best individual is not changed, the program is finished. Otherwise, the next iterative operation starts from the step 2.

4. RESULTS AND DISCUSSION

4.1. Results of FEM model and analysis for the defects of beam blank

The mathematical model of heat transfer and solidification, based on the finite difference technique, can predict the temperature distribution and the solid shell profile in continuous casting. The

Table 1. Input process parameters for continuous casting process.

	Units	Values
Beam blank dimensions	mm	550×450×90
Metal		Q235b
Mold length	mm	700
Mold water consumption	l/min	5600
Sprays 1 length	mm	660
Sprays 1 water consumption	l/min	253
Sprays 2 length	mm	1500
Sprays 2 water consumption	l/min	188
Sprays 3 length	mm	2400
Sprays 3 water consumption	l/min	114
Sprays 4 length	mm	2400
Sprays 4 water consumption	l/min	47
Sprays 5 length	mm	2400
Sprays 5 water consumption	l/min	21
Distance from meniscus surface to unbending point	m	19.14
Casting speed	m/min	0.98
Pouring temperature	°C	1549
Liquidus temperature	°C	1519
Solidus temperature	°C	1464

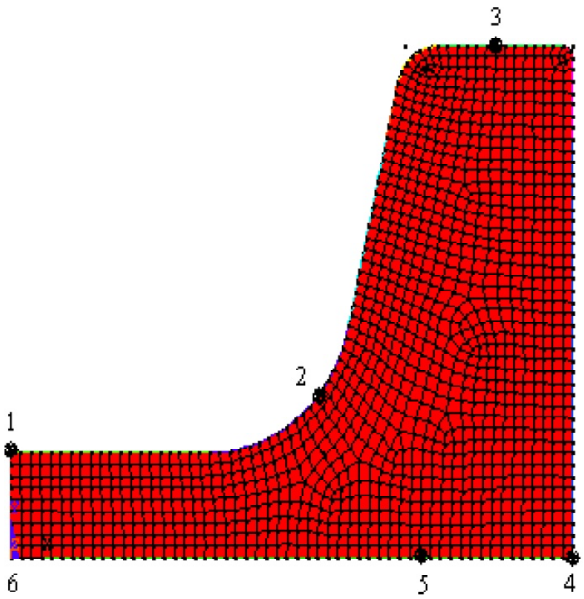

Fig. 1. Finite element grids and some representative point on the section of beam blank.

model is based on the equation of heat conduction in unsteady state. The mathematical model of thermal stress can predict the strain and stress distribution in the strand shell and provide very key information to the strand quality, especially to the crack forming. For non-linear mechanical analysis the two-dimensional, transient, thermo-elastic-plastic material model with bilinear isotropic hardening is used [1,2].

This work employed the real values of operating parameters in JINXI Iron and Steel Co. After the beam blank continuous caster put into production, there had been some longitudinal surface cracks on the web. The aim of this work is to simulate the solidification process of continuous casting, to find the reasons for defects, and then to optimize the process parameters. The input process parameters are presented in Table1. Fig. 1 shows the finite element grids and some representative points on the section of beam blank. Figs. 2 and 3 show

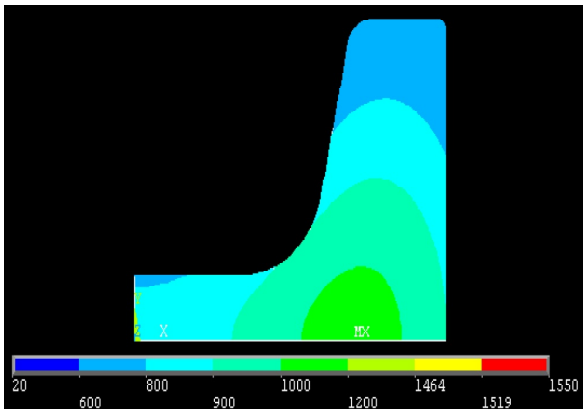

Fig. 2. Temperature contours at unbending point (1171s).

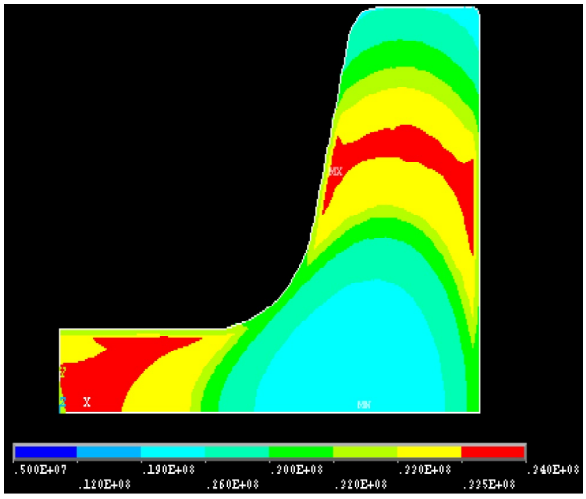

Fig. 3. Equivalent stress contours at unbending point (1171s).

Table 2. Comparison of the optimized water consumption between two optimization methods.

	Spray 1	Spray 2	Former Spray 3	Latter Spray 3	Spray 4	Spray 5	Total
Initial water consumptionl/min	253	188	57	57	47	21	623
Optimized water consumption by the zero order optimization method l/min	230.9	171.3	59.7	52.9	24.1	7.2	546.1
Optimized water consumption by MOGA combined with the FEMl/min	232.8	175.1	58.4	51.8	15.4	5.9	539.4

continuous contours of the equivalent temperature and stress at unbending point respectively.

In order to assure the product quality, the process of continuous casting must follow some metallurgical constraints. The following metallurgical criteria represent the product quality and the process feasibility of beam blank continuous casting: (1) The shell thickness at the mold exit must be bigger than the certain minimum value. This constraint avoids breakout caused by extraction stress and liquid ferro static pressure. The minimum value of beam blank is considered to be about 12 mm. (2) For the beam blank, the solidification of the steel should be complete before the end of the secondary cooling zone. (3) The surface temperature during the secondary cooling zone should be locate between 800 °C and 1200 °C in order to avoid the cracks caused by great fluctuation of temperature. (4) The reheating occurs when the strand passes from a cooling zone with a higher cooling rate to one with a lower rate. The reheating may cause the development of tensile stress at the solidification front, and can induce cracks. In order to ensure the quality, the maximum reheating must be less than 120 °C. (5) In order to avoid transverse surface cracks, the temperature of the strand surface at the unbending point must be outside the low ductility trough, that is to say, the temperature should be either higher than the limit of the ductility trough or lower than the low limit.

According to the FEM analysis, the first four constraints can be satisfied, but the fifth rule can not be met. Therefore, the key factor that causes the surface cracks on the web can be found out. That is: the heat flow density on the web is too much high. The high heat flow makes the temperature at unbending point less than the constraint; moreover the surface temperature has a great fluctuation on the transverse web, so the stress and strain have quite high values here. In the center of the surface web, the temperature is only 780 °C, which is just

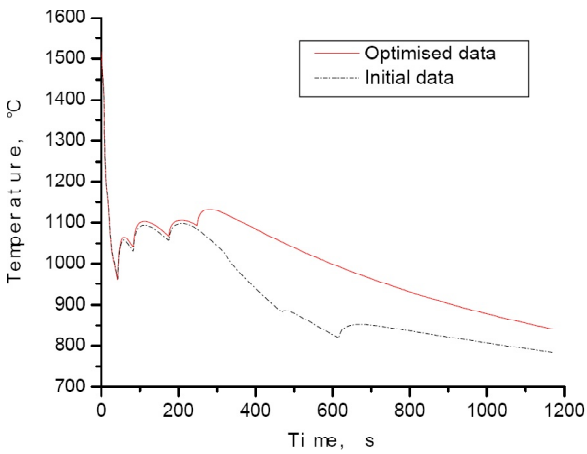

Fig. 4. Comparison of initial and optimized temperature on the surface web.

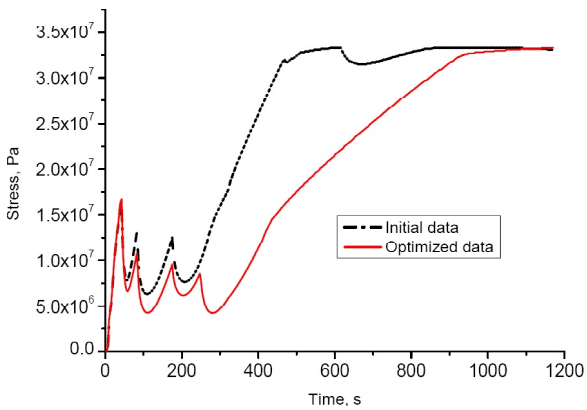

Fig. 5. Comparison of initial and optimized stress on the surface web.

on the point of the critical lowest plasticity. The temperature has a increasing of 120 °C from the center to the end of the web, which must induce great tensile stress. Therefore when the strand passes by the unbending point, under the influence of unbending force and the composition of the steel, the surface cracks can be caused or developed on the surface web.

4.2. Results of optimizing methods

To avoid the surface cracks on the web, the cooling system should be modified. The optimization method of MOGA combined with the FEM is used to optimizing the cooling parameters. In order to validate this method developed in this paper, the zero order optimization method in ANSYS software is applied to calculate this project again. During the two optimization processes, three types of variables are employed: design variables, state variables and objective function. The design variables contain the water consumption values of each secondary cooling zone. The state variables consist of the metallurgical constraints listed above. The objective function is the sum of the water consumption values of secondary cooling zone.

The comparison of the optimized water consumption between two optimization methods is shown in Table 2. From the table, it can be found that in these two methods the water consumption in each secondary cooling zone is very similar. In our earlier work the zero order optimization method was used to optimize the cooling parameters in continuous casting [3]. Therefore, the optimized parameters used the method of MOGA combined with the FEM is crediteble. Moreover, compared with the zero order optimization method, the water consumption is decreased 5.7 l/min.

Fig. 4 shows the comparison of initial and optimized temperature on the surface web used the method of MOGA combined with the FEM. Fig. 5 shows the comparison of initial and optimized stress on the surface web. It can be found the temperature at the unbending point is in a range of 836~908 °C on the surface web. This range is higher than the limit of the ductility trough. The curves of the optimized surface temperature and stress are smoother than initial condition, which imply the less possibility to generate surface cracks. The first four metallurgical constraints also can be met.

Now, online verifying of this optimization project has been developed. The probability of surface cracks has been reduced from 5% to 0.5%. It can be proved that this optimizing method is very useful and efficient to control the surface cracks on the web. Moreover, the water consumption of secondary cooling zone can be saved 13.4%. So this optimum cooling system can make it possible to run the caster at its maximum productivity, minimum cost and to cast defect free products.

5. CONCLUSION

(1) In this paper, a new parameters optimizing method is set up combined the multi-objective genetic algorithms (based on MATLAB) with finite element method (based on ANSYS) to search out the optimum processing parameters for beam blank continuous casting. The finite element method is used to calculate the thermo-mechanical process for beam blank continuous casting. The multi-objective genetic algorithm is used to search out the optimum processing parameters for beam blank continuous casting.

(2) Online verifying of this optimization project has been put in practice, which can prove that it is very useful and efficient to control the real production.

(3) This developed optimizing method, taking full advantage of the feature of FEM that computes precisely and the feature of MOGA that search the optimal solution globally and rapidly, provides a method for solving the complex and large engineering problem, especially to the multi-objective optimizing problems, for it need not change multi-objectives into single objective, the constraints not limited to the format of $a<x<b$.

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