Thermal barrier coating processing based on improved ant colony algorithm Process optimization and verification

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Abstract. This paper presents a new method for electrolyte-assisted UV laser processing of thermal barrier coating materials. Under a certain thickness of the electrolyte layer, the ultraviolet laser beam is focused on the surface of the workpiece, the laser galvanometer realizes the rapid rotation of the thermal barrier coating material by the ultraviolet laser beam, and the "two-photon absorption" removes the matrix of the thermal barrier coating material, and collapses. The cavitation bubble action avoids the secondary adhesion of the processed material, meets the processing precision requirement (±0.05mm), and realizes the cold processing of the non-recast layer of the thermal barrier coating micropores. The improved ant colony algorithm is used. The minimum diameter difference is the objective function, the upper and lower diameter difference and the upper and lower machining precision are the constraints. The thermal barrier coating processing optimization model is established, and the process parameters are optimized and experimentally verified.

1. Improvement of ant colony algorithm

Ant colony algorithm has been widely used in many fields, but the ant colony algorithm has the disadvantages of stagnation and partial optimality. At present, for the rapid optimization of algorithms and the need to avoid falling into local optimal problems, the corresponding improvement of ant colony algorithm is needed, such as improvement of path selection strategy, improvement of pheromone update strategy, introduction of mutation strategy, addition of random disturbance. Strategies and integration with other algorithms to improve the speed of algorithm optimization.

1. Improvement of pheromone update strategy: Through the discovery of the social behavior of ant population, ants use pheromone to realize information exchange and cooperation between individuals and between individuals and the environment. In the development of ant colony algorithm improvement strategy, the improvement of pheromone has done a lot of research. It is found that the different ways of updating the pheromone have great influence on the performance of the ant colony algorithm, which will affect the convergence speed and optimization ability of the algorithm. However, in the pheromone update, if the global pheromone is updated, the algorithm is not easy to achieve convergence. Conversely, if the pheromone of a single ant loop path is updated, the pheromone on that path will accumulate too much and the algorithm will fall into local optimum. Therefore, the improvement strategy of ant colony algorithm should take these two aspects into consideration, and ensure that the algorithm can quickly find the optimal solution under the condition of convergence. It is usually obtained by integrating global pheromone update and local pheromone update. Satisfying result.
2. Improvement of search speed: When searching for ant colony algorithm, positive feedback will gradually increase the concentration of pheromone on the suboptimal solution path, and subsequent ants may choose a suboptimal solution path with high concentration. At the same time, the pheromone is constantly volatile, and the concentration of the sub-optimal solution pheromone is increasing, so that the chances of the subsequent ants finding the global optimal solution are gradually reduced, the optimal path cannot be found, the search range is narrowed, and then into the local optimal, the stagnation occurs. Therefore, the search speed is a defect that limits the development of ant colony algorithm. At the same time, the search speed has always been the bottleneck of the application of ant colony algorithm in large-scale optimization problems. Therefore, it is necessary to study the appropriate search speed and search space, and take corresponding improvement measures. To improve the performance of the ant colony algorithm.

3. Improvement of path selection strategy: In order to reduce the probability that the algorithm falls into local optimum and improve the ability of the algorithm to find the optimal, it is necessary to design a suitable path selection strategy. Adjusting the path of the ant colony algorithm is to guide the ant's initial optimization process through a state transition rule, so that it can find a feasible solution faster, and accumulate on this basis to achieve the effect of speeding up the convergence. At the same time, the random search operation is added, which is beneficial to the global optimal solution search of space, and can effectively overcome the shortcomings of the ant colony algorithm which is slow in evolution and easy to fall into local optimum. The ant will select the path of pheromone with a large probability, which makes the search in the initial state may be on a locally short path with a high probability, which makes the ant colony search lose diversity. Therefore, in order to enable the ant to select more paths in the initial optimization process, the pheromone volatilization factor can be set. When the pheromone concentration does not reach a certain threshold, the existence of the optimal solution is ignored, and only when the pheromone reaches the threshold Let the ants tend to accumulate more paths of information under this machine of pheromone. Here, the kth ant can be converted from state i to state j with the following probability:

![Math equation](image)

In the middle:  
- $q$ ----- a random number evenly distributed in the interval [0, 1]
- $q_0$ (0 < $q_0$ < 1) ----- a parameter, J is a random variable generated according to the given selection rule.

4. Add random perturbation strategy: The ant colony algorithm has the disadvantages of slow search speed, easy to fall into local optimum, and prone to stagnation. In order to overcome the stagnation in the search process, a random perturbation strategy can be adopted, and the probability of random selection is dynamically adjusted during the evolution process. This increases the chances of path selection and helps to overcome stagnation in the search process. What is usually done in the ant colony algorithm is the combination of deterministic selection and random selection. This deterministic choice causes the ant to always choose the path with the largest transfer coefficient, while the random selection leads to a strong random when calculating the transfer coefficient. Sex. It is the combination of the two that complements each other to make the algorithm have a stronger global search ability and truly improve the algorithm.

5. Fusion with other algorithms: Ant colony algorithm has many advantages. The strong positive feedback ability is a point that can be applied to the improved algorithm. The positive feedback of the formal ant colony algorithm makes the algorithm accumulate a certain amount of pheromone in the later stage. It can speed up the evolution of the algorithm and make the algorithm reach a convergence state quickly. But at the same time, we also found that the ant colony algorithm also has better coupling ability, so we can use the positive feedback of ant colony algorithm and good coupling ability to fuse with other algorithms, which is also a good way to improve ant colony algorithm. The fusion algorithm can show good properties. The fusion of ant colony algorithm and genetic algorithm can not only utilize the fast convergence performance of ant colony algorithm, but also make full use
of the fast global search ability of genetic algorithm to achieve complementarity. The fusion of ant colony algorithm and p-Opt local search algorithm improves the efficiency and accuracy of the best path in each environment. The ant colony algorithm can also be integrated with the neural network, which complements the broad mapping ability of the neural network and the fast global convergence of the ant colony algorithm, presenting characteristics that are not unique to a single algorithm.

In addition, the hybrid algorithm combined with the ant colony algorithm has been greatly developed. The advantages and disadvantages of various algorithms can be used to complement the shortcomings of various algorithms, and the advantages of the respective algorithms can be used to solve practical problems.

2. Thermal barrier coating processing optimization model
The above lower diameter difference is minimized as the optimization target, and the thermal barrier coating processing optimization model is established by taking the process parameters and other experimental results as the constraints. The model can be expressed as:

\[
\begin{align*}
\text{Min } & \text{ UDDD } \% \left(\text{UDDD}\right) \\
\text{s.t. } & 0 \leq \text{ULDD} \leq 50 \% \left(\text{ULDD}\right) \\
& 0 \leq \text{DLDD} \leq 50 \% \left(\text{DLDD}\right) \\
& 0 \leq \text{ULDD} \leq 50 \% \left(\text{ULDD}\right) \\
& -50 \leq \text{UMA} \leq 50 \% \left(\text{UMA}\right) \\
& -50 \leq \text{DMA} \leq 50 \% \left(\text{DMA}\right) \\
630 \leq & x_1 \leq 950, x_1 = 0.01*i_1 \\
30 \leq & x_2 \leq 46, x_2 = 1*i_2 \\
10 \leq & x_3 \leq 26, x_3 = 1*i_3 \\
10 \leq & x_4 \leq 42, x_4 = 1*i_4 \\
i_j = & 1,2,3,4, j=1,2,3,4
\end{align*}
\]

3. Process optimization method
The improved ant colony algorithm is used to optimize the process parameters. The specific steps are as follows:

1. Adaptive pheromone volatilization factor. In the process of searching the path of the ant colony algorithm, if the pheromone strength is always a constant, its size will not have a great impact on the performance of the algorithm; but if the pheromone intensity is dynamically changed during the search process, the performance of the algorithm will be have an impact. Therefore, in order to avoid the stagnation phenomenon in the search optimal solution process, the pheromone on the optimization
path is dynamically adjusted by the adaptive pheromone volatilization factor to improve the global search ability and search speed of the algorithm.

The adaptive variation formula of pheromone volatilization factor is as follows:

$$\rho(t) = \begin{cases} 
0.95 * \rho(t-1), & \text{if } \rho(t) \geq \rho_{\text{min}} \\
\rho_{\text{min}}, & \text{otherwise} 
\end{cases}$$  \hspace{1cm} (3-1)

In the middle: \(\rho_{\text{min}}\) the minimum value of the pheromone is expressed, the purpose of which is to prevent the convergence speed of the algorithm from being slow due to the fact that \(\rho(t)\) is too small.

2. Adaptive transfer probability. In the process of improving the search path of ant colony algorithm, in order to avoid the ant later choosing the same path to make the algorithm fall into the stagnation state too early, a new adaptive factor is introduced in (3-2) to explore the route of low concentration pheromone through the new incentive, so as to suppress the positive feedback and strengthen the global search capability.

The transfer probability formula is as follows:

$$p(t) = \frac{\tau(i) * \exp \left( - |\tau(i) - \tau_{\text{regu}}| \right)}{\sum_{j=1}^{n} \tau(j) * \exp \left( - |\tau(j) - \tau_{\text{regu}}| \right)}$$  \hspace{1cm} (3-2)

Among them, \(\tau_{\text{regu}}\) is a regulatory factor, usually set to a smaller value than \(\max \{ \tau(i) \}\). The smaller the value is, the greater the probability of accessing smaller pheromone concentration paths are.

3. Variable scale chaotic search. Chaos optimization is a new optimization algorithm, which improves the efficiency of stochastic optimization algorithm by using randomness, universality and initial sensitivity of chaotic sequences. The variable scale chaotic search algorithm is integrated into the ant colony algorithm, and a better solution is found near the current global optimal solution. As the ant colony algorithm is carried out, the search range of chaotic operator is gradually reduced, and the aim of improving the search accuracy is to prevent the local optimum in the early stage of ant colony search and improve the search accuracy at the later stage.

The formula of variable scale carrier based on chaotic sequence is as follows:

$$x(t) = \begin{cases} 
(1 + 2 * r(t) * (\text{ChaosSeq} - 0.5), & p \geq p_0 \\
(1 + 2 * \text{Loc}(t) * (\text{ChaosSeq} - 0.5), & p < p_0 
\end{cases}$$  \hspace{1cm} (3-3)

Among the formula, \(x(t)\) is the self variable value after the superposition of chaotic sequence, \(r(t)\) is a variable scale chaotic search radius, \(\text{Loc}(t)\) is a local chaos search radius, and \(\text{ChaosSeq}\) is a chaotic sequence.

4. Optimization results and verification

The minimum diameter difference is the optimization target, the diameter difference of the length and length, the difference between the length and length, the machining precision and the machining precision are the constraints. The optimization method based on the improved ant colony algorithm is adopted to obtain the optimal process parameters, the optimal value and the experimental results, such as table 4.1.

| Table 4.1 Optimal process parameters and optimal values |
The optimized process parameters are used to verify the perforation. The optimized process parameters are repeated three times and the average value of the three times is the experimental value. The optimization results are basically the same as the experimental results. The optimization results are compared with the experimental results, such as figure 4.1. The electrolyte assisted UV laser optimization process parameters processing samples, such as figure 4.2, are compared. The error is within the range of allowable value (less than 15%), and the test results meet the requirement of precision (+ 0.05mm). Thus, the optimization method based on improved ant colony algorithm is proved to be efficient to find the optimal experiment scheme.

| Process parameters | Laser power factor | Laser pulse frequency | Laser cutting speed | Laser cutting spacing | ULDD | DLDD | UDDD | UMA | DMA |
|--------------------|-------------------|----------------------|---------------------|-----------------------|-------|------|------|-----|-----|
| Optimization results | 950 (%) | 46 (kHz) | 10 (mm/s) | 28 (μm) | 18 (μm) | 33 (μm) | 48 (μm) | 50 (μm) | 2 (μm) |
| Experimental result | 950 (%) | 46 (kHz) | 10 (mm/s) | 28 (μm) | 16 (μm) | 35 (μm) | 42 (μm) | 47 (μm) | 2 (μm) |

Figure 4.1 Response optimization, experimental results comparison chart
5. Conclusion

The ant colony optimization algorithm is introduced and the improved strategy of ant colony algorithm is analyzed. The improved ant colony algorithm was used to optimize the experimental data, and the optimization model of thermal barrier coating process based on improved ant colony algorithm was established. The experimental verification was carried out and good processing results were obtained. The improved ant colony algorithm was used to establish the thermal barrier coating processing optimization model, and the best experimental scheme was found efficiently. The optimization results show that the electrolyte assisted UV laser cutting thermal barrier coating microstructure can obtain better microporous structure. The machining accuracy is ±0.05mm, which meets the process requirements. Through theoretical analysis and process experiment research, it shows that electrolyte-assisted UV laser processing technology has considerable engineering application prospects.

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