Research on Electrolyte Jet Assisted Laser Micromachining Technology

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Abstract. For the traditional laser processing method, processing defects such as recasting layer, microcrack and high concentration of heat affected zone are inevitably generated, which reduces the surface quality and service life of the microstructure. In this paper, the electrolyte jet assisted laser micromachining technology is proposed. This technology applies the laser beam and the corrosive electrolyte jet beam coaxially to the workpiece. At the same time as the laser acts, the corrosive electrolyte jet continuously scour, cool and slightly corrode the processing area. The effect can reduce the thickness of the recast layer, reduce the number of microcracks, and eliminate the high concentration of the heat affected zone. In this paper, the causes of recasting layer in laser processing are analyzed firstly. The material removal mechanism involved in the laser jet assisted laser micromachining and the mechanism of laser coupled electrolyte jet beam are studied. The flow field in the laser jet assisted laser drilling process is established. And the mathematical model of the temperature field; the effects of laser pulse energy, laser repetition frequency, electrolyte concentration and electrolyte jet velocity on the thickness of material recast layer were studied, and the basic processing technology of electrolyte jet assisted laser micromachining was preliminarily mastered, laying the foundation for further research on electrolyte jet assisted laser micromachining technology.

1. Electrolyte jet assisted laser micromachining mechanism

1.1 Mechanism of laser impact force in electrolyte jet

The high heat of the laser causes the surface material of the workpiece to be converted from solid to liquid until a large amount of vapor particles are generated on the surface of the workpiece. The vapor particles collide with each other to propagate away from the surface of the target, and the layer of vapor particles only a few microns away from the surface is called the Knudsen layer. The vapor particles continue to absorb the laser energy and eventually ionize to form a plasma. The generated plasma has a strong absorption effect on the laser. When the absorbed laser energy is sufficiently large, the plasma and the material vapor rapidly expand to propagate at a supersonic speed to generate a high voltage. Shock wave, in the electrolyte jet assisted laser processing, the presence of an electrolyte confinement layer on the surface of the workpiece limits the external expansion of the high-pressure shock wave and generates a strong reaction force to the workpiece. When the laser is strong enough to propagate from the surface of the workpiece at supersonic speeds along the direction of the laser the plasma generation ,the plasma expansion wavefront is called the laser-supported blast wave (LSDW) [1].

In addition to the blast wave reaction force formed by the plasma expansion wave front, the pressure generated by the hollow bubble cavitation in the composite processing process promotes the
processing at the same time. The electrolyte jet assists in the laser processing process, the electrolyte constrained layer is heated, and some of the electrolyte vaporizes to form vacuoles, which will be generated up to the surface of the workpiece. 140MPa~180MPa, such high impact force will form fine pits on the surface of the workpiece.

In summary, it can be seen that the impact force acting on the surface of the workpiece during the laser jet assisted laser processing is mainly composed of the shock wave reaction force of the Knudsen layer plasma, the hollow bubble cavitation [2] impact force and the jet impact force of the processing region solution, and electrolysis. The mechanism of laser impact force in liquid jet, as shown in Figure 1.

Figure 1 Processing mechanism of laser impact force effect in electrolyte jet

1.2 Laser beam coupled electrolyte jet beam mechanism
The laser beam is emitted by the laser and then polymerized by the convex lens. After the different refraction of the air layer, the glass layer and the electrolyte layer, the laser jet is injected at a certain angle and totally reflected at the interface between the electrolyte and the air, and finally acts on the surface of the workpiece. In order to make the total reflection of the laser beam in the jet of the electrolyte, it is necessary to adjust the distance between the center of the appropriate lens and the upper surface of the window glass and the maximum angle of incidence of the total reflection of the laser in the jet of the electrolyte to meet certain optical transmission conditions. By selecting the appropriate laser focus front radius and the convergence convex lens focal length, it is possible to theoretically achieve total reflection of the laser beam in the electrolyte jet. The laser beam couples the electrolyte jet beam mechanism, as shown in Figure 2.

Figure 2. Laser beam coupled electrolyte jet beam mechanism

The mechanism of laser impact force and the mechanism of laser coupled electrolyte jet beam involved in electrolyte jet assisted laser processing are deeply explored, which lays a theoretical foundation for the further study of electrolyte jet assisted laser micromachining technology.

2. Physical model establishment and simulation result analysis of fluid jet assisted laser drilling process flow field
During the laser jet assisted laser processing, the electrolyte jet penetrates into the surface of the workpiece after propagating in the air, which is a two-phase flow problem in the multiphase flow (gas-
liquid two-phase flow). The simulation was performed using the VOF model. The physical model of the jet of electrolyte passing through the air to the surface of the workpiece during the drilling process, as shown in Figure 3.

![Figure 3 Physical model diagram of gas-liquid two-phase flow in punching process](image)

The flow field simulation is simplified to 1/4 of the physical model, and the calculation cost is reduced under the premise of ensuring accurate calculation. The workbench is used to build the model and mesh, as shown in Figure 4.

![Figure 4 Flow field model and grid](image)

The electrolyte jet inlet is set as a compressible fluid, the inside of the model is an incompressible fluid, and the bottom surface of the model is a wall. The jet velocity direction is the normal direction of the inlet and is perpendicular to the upper surface of the workpiece. According to the established physical model and the set initial conditions, the unsteady implicit separation solution is used to solve the flow field simulation in fluent 14.0, and the flow field simulation results of the electrolyte jet during the machining process are shown in Figure 5.

![Figure 5 Flow field simulation results](image)

From the graph velocity vector diagram (a) and the velocity cloud diagram (b), the velocity value of the electrolyte jet during processing and the velocity distribution of each region are known. The velocity of the electrolyte jet before contacting the upper surface of the workpiece is uniform in cross section. Maintaining 12m/s, the velocity is gradually reduced as it approaches the surface of the workpiece, and the velocity at the point of contact between the jet axis and the workpiece surface is finally reduced to 0m/s; from the jet pressure cloud diagram (d), the surface pressure of the workpiece
is along the intersection with the jet axis gradually decreases outward, and the pressure is maximum at the intersection. This pressure distribution is favorable for the erosion of the melt during processing; the phase diagram of the electrolyte jet and air is as follows (c), the red part is air, blue For the electrolyte jet, the shape changes from a regular cylindrical shape to a diverging shape during the jet transport of the electrolyte, and the thickness of the liquid when contacting the surface of the workpiece is very thin, and the change of the shape of the electrolyte jet is favorable for punching. During the processing, the local area of the processing is cooled, thereby reducing the concentration of thermal stress.

3. Establishment of temperature field physical model of electrolyte jet assisted laser drilling and analysis of simulation results

Electrolyte jet assisted laser microfabrication compared to conventional air laser processing, not only produces various thermal phenomena between the laser and the material (heat transfer, heat convection, heat radiation, etc.), but also the electrolyte jet to the processing area during processing continuous scouring produces impact force effects, forced convection heat transfer effects of electrolyte jets, and the like. When the electrolyte jet assists the laser drilling process, there is only axial relative motion between the jet and the workpiece, and the jet acts perpendicularly on the surface of the workpiece, and the physical model diagram is established, as shown in Figure 6.

Figure 6 Schematic diagram of the physical model

When using ANSYS to simulate the machining process, the more the number of units is and the smaller the unit size is, the higher the configuration requirements of the computer are. Under the premise of ensuring the correct analysis results, in order to reduce the amount of simulation calculation, this paper builds a model for 1/36 workpieces. In the meshing, the laser spot diameter of the laser reaches the micron level when the electrolyte jet assisted laser drilling is simulated. In order to ensure the accuracy of the solution and the calculation amount in the simulation process, the model is divided into different unit sizes. The overall unit size is 1/3 of the spot diameter, and the electrolyte jet beam influence area is 1/16 of the spot diameter, and a finite element model diagram is obtained, as shown in Figure 7.

Figure 7 finite element model diagram after meshing
4. Effect of processing parameters on material removal

Figure 8 Effect of laser repetition frequency on the thickness of recast layer
It can be seen from the figure 8 that as the repetition frequency of the laser increases, the thickness of the recast layer gradually decreases. This is because as the repetition frequency increases, the number of pulses acting on the workpiece increases, causing the molten material to remain in a molten state for an increased time, and the electrolyte jet is more, the residual melt is sufficiently washed and corroded. But the excessive repetition frequency and the small pulse energy are reduced, which reduces the amount of material removal. Therefore, the appropriate laser repetition frequency should be selected during the composite processing.

It can be seen from the figure that as the laser energy increases, the thickness of the recast layer first decreases. When the laser energy is greater than 300 mJ, the thickness of the recast layer increases with the increase of the laser energy. This is because as the laser energy increases, the material in the processing area is enhanced by gas-liquid phase change, and the liquid material remains for a long time. When the electrolyte jet is washed away from the substrate, the residual amount of the melt decreases and the thickness of the recast layer gradually decreases, but when the laser energy is too large At the same time, the gas phase material of the material increases, and the water mist generated when the jet contacts the processing region increases, which reduces the hot working effect of the laser, and at the same time, more and more molten material is generated, and the electrolyte jet saturates the melting ability of the molten material. The residual slag will increase continuously, and the thickness of the recast layer of the hole will gradually become larger. From the analysis, it can be seen that in order to reduce the thickness of the recast layer and improve the surface quality during the composite processing, excessive laser energy should not be selected. For composite processing, at the same time, according to different processing purposes, select the electrolyte jet velocity that is compatible with the processing laser energy, when

Figure 9 Effect of laser energy on the thickness of recast layer
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Figure 10 Effect of electrolyte concentration on the thickness of recast layer

Figure 11 Effect of jet velocity on the thickness of recast layer

It can be seen from the figure that the thickness of the recast layer gradually decreases with the increase of the jet velocity of the electrolyte and the concentration of the electrolyte, because the jet velocity becomes higher, the scouring effect of the melt and the chemical corrosion effect of the melt are enhanced, and the electrolyte concentration is increased. The increase causes the chemical corrosion effect of the melt to increase. As the concentration of the electrolyte increases, the thickness of the cast layer gradually decreases, and finally the chemical corrosion effect is saturated, and the thickness of the recast layer tends to be stable; as the jet velocity reaches 16 m/s, the thickness of the cast layer has increased. This is because when the jet velocity is large, the forced convection effect is too strong, and the melt is cooled too fast. Before it is washed, it begins to condense on the hole wall to form a recast layer, and the thickness of the cast layer is re-cast. Increase; jet velocity and electrolyte concentration too large will make the laser pulse energy attenuation amount larger, reduce the composite processing efficiency, and choose the appropriate electrolyte jet velocity and electrolyte concentration under the premise of ensuring the quality of the machined surface.

5. Conclusion

Based on the laser processing mechanism, the material removal mechanism involved in the laser jet assisted laser micromachining and the laser coupled electrolyte jet beam mechanism were studied. The jet flow field and the perforation temperature during the laser jet assisted laser drilling process were established. The mathematical model of the field has obtained the basic processing technology of the electrolyte jet assisted laser micro-machining technology. The specific work and conclusions are as follows:

(1) This paper analyzes the causes of recasting layer in laser processing and the progress of laser re-casting layer removal at home and abroad, and studies the material removal mechanism and laser-coupled electrolyte jet beam mechanism involved in electrolyte jet assisted laser micromachining;

(2) The mathematical model of the medium jet flow field and the perforation temperature field of the electrolyte fluid assisted laser processing was established, and the iterative calculation was performed on the fluent 14.0 and ANSYS software by the finite element method. The evolution process and the composite of the hole were obtained. The influence of processing parameters on the shape of the hole, the actual drilling process is carried out by using the simulated machining parameters, and the hole shape and size are compared. The consistency of the two is good, and the effectiveness of the simulation is verified. Numerical simulation provides theoretical guidance for the electrolyte jet assisted laser drilling test.
(3) The effects of electrolyte concentration, electrolyte jet velocity, laser pulse energy, laser repetition frequency on material removal and recast layer thickness were investigated. The basic process rules of electrolyte jet assisted laser micromachining were preliminarily obtained. Further research basis of electrolyte jet assisted laser micromachining technology.

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