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ELIMINATION OF THE DEFECTIVE LAYER AND STRESS CONCENTRATORS DURING MICROMACHINING OF HOLES IN THIN SHEET BLANKS OF METAL CELLULAR PANELS

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ABSTRACT

Thin-sheet blanks made of aluminum (in particular, AMg2-N), titanium (VT-15, VT-19) or stainless (12X17) alloys are widely used in the production of honeycomb panels in the aviation and space industries. Foil (thickness 0.025-0.055 mm) is used for the production of fillers for cellular sandwich panels; it is pre-perforated with holes of 0.05-0.18 mm and laid out in a corrugated box with adhesive strips. The possibility of making holes by the laser jet method is considered, as it precedes the occurrence of mechanical damage and thermal defects of the surface adjacent to the treatment zone.

It is shown that the Water Jet Guided Laser (WJGL) is an effective and efficient method of obtaining profile holes in the fillers of cellular panels and in the panels themselves, which is characterized by high productivity and allows obtaining holes without thermal and mechanical defects. The method can be used both for foil fillers and for metal panels made of stainless steel up to 1.5 mm thick.

1. INTRODUCTION

Foil (thickness 0.025-0.055 mm) is used for the production of fillers for cellular sandwich panels; it is pre-perforated with holes of 0.05-0.18 mm and laid out in a corrugator with adhesive strips. As a rule, processing of such blanks is carried out mechanically (for perforation, this is the most productive and effective method of forming an array of holes, which do not require high accuracy requirements); less often, holes are formed using a laser beam. In the first case, there are random breaks in the material, in the second case, a defective layer is formed on the end; the hole itself also has an arbitrary shape, and the spread of material destruction is unpredictable. Sometimes one of the elements of the sandwich is subjected to perforations - holes of 0.8-1.2 mm are made with a step proportional to the walls of the cellular filler (5x5...12x12 mm). The purpose of the work is to assess the possibilities of preventing the reduction of physical and mechanical properties of workpieces due to processing with a hybrid tool - laser-jet impact.

2. EXPOSITION

Jet-laser cutting (another name is Water Jet Guided Laser) is the treatment of material with a combined thermal-hydrodynamic flow of a certain shape, as a result of which the barrier - the processed surface - perceives a continuously changing impact hydrodynamic and temperature load [1]. The alternation of these processing phases occurs whenever, after a pulse of laser radiation, the surface of the barrier in contact with the jet, in the zone with the largest flow velocity gradient, instantly overheats and melts with the formation of a supersaturated vapor cavity; in the pause between pulses, this cavity in the flow closes, and a shock wave spreads over the surface, with simultaneous intense cooling of the affected zone. At the same time, the temperature in the cutting zone in the absence of refrigerant supply according to [2] is:

$$T(x,y,z,t)=\frac{P}{\pi^{\frac{3}{2}}\rho c}\int_{0}^{l}\frac{e^{-\frac{(x-v(t-\tau))^{2}}{4a\tau+A^{2}}-\frac{y^{2}}{4a\tau+B^{2}}}}{\left[(4a\tau+A^{2})(4a\tau+B^{2})a\tau\right]^{1/2}}\cdot \tag{1}$$
$$\cdot\left[e^{-\frac{z^{2}}{4a\tau}}-h(\pi a\tau)^{\frac{1}{2}}exp\left(\frac{z}{2(a\tau)^{\frac{1}{2}}}+h(a\tau)^{\frac{1}{2}}\right)\cdot e^{hz+h^{2}a\tau}\right]d\tau$$

where ρ, c, λ - density, specific heat capacity and coefficient of thermal conductivity of the material,

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respectively; $a = \frac{\lambda}{c\rho}$ - thermal conductivity of the material; h – coefficient of heat transfer from the surface; A, B – major and minor semi-axis of an elliptical beam; $P = \pi qAB$ - the power of the laser emitter.

The supply of ultra-high-pressure fluid requires consideration of boundary conditions

$$c\rho\frac{dT}{dt} - \lambda\Delta T = \frac{(1-R_0)kP}{\pi AB}exp\left[-2\left(\frac{(x-vt)^2}{a^2}+\left(\frac{y}{b}\right)^2\right)\right]\cdot exp(-kz);$$

$$\lambda\left.\frac{dT}{dz}\right|_{z=0} = \alpha(T)(T-T_p); \qquad (2)$$

$T(x,y,z,t) = T_0$ when approximating the growth of the heat transfer coefficient depending on the species $h(T) = h_m exp\left(-\frac{(T-T_m)^2}{\Delta T^2}\right)$ (according to [3]), that when performing the numerical solution of equation (1), will give zones of sharp temperature drop at the place of coolant supply, and, depending on the flow rate of the cooler and the efficiency of heat removal, the distribution of temperature fields can be significant.

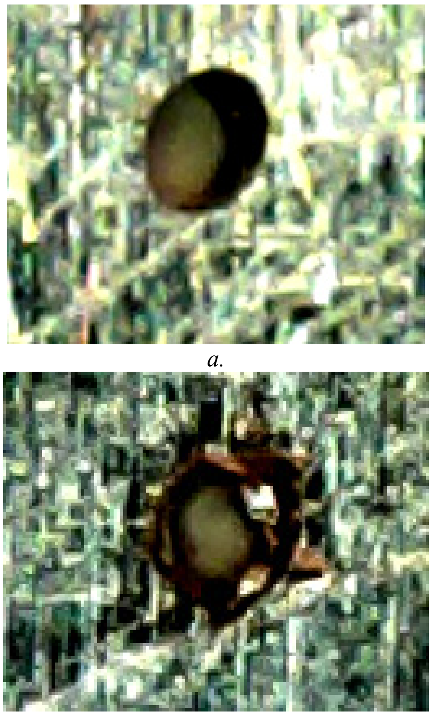
If we assume that the radiation power is distributed uniformly on some processed surface, and the radiation enters along the normal, then in time δt energy will reach the surface $W\delta t$. For the length of the formed groove S, the volume of evaporated material will be Sbl. Based on the law of conserved energy, we can write $S\rho bl \cdot h = W\delta t$; h - the amount of heat required to evaporate a unit mass of material. Transforming this expression and assuming that $\delta t \to 0$, we will have the growth rate of the groove in the form $\frac{ds}{dt} = \frac{W}{bl\rho h}$. The last equation proves that for any material the limiting rate of groove growth is proportional to the energy release density W / A. Then the length of the groove at an arbitrary moment of time t will be $l(t) = \frac{E(t)}{h\rho Sb}\int_0^t Wdt$ where E(t) - the total energy released by the source over a period of time $(0,t)$.

Therefore, in the limiting mode of evaporation, the size of the groove depends on the total energy arriving at the surface. On the other hand, there is a certain transfer of energy deep into the material due to thermal conductivity. This phenomenon leads to the formation of a destructive layer - a layer with changed physical and mechanical properties. The problem of the movement of the boundaries of the phase separation taking into account thermal conductivity is known as Stefan's problem.

The results of calculating the expansion of the zone of thermal destruction for the analyzed materials under laser and laser-jet exposure, from which it becomes obvious that neither a significant increase in the zone of thermal influence nor an active increase in temperature occurs under the action of the liquid flow. Therefore, it is possible to localize the action of a high-energy flow in a small area with the simultaneous formation of a corresponding hole of destruction, for example, an opening with a diam. D. At the same time, a change in the conditions of the combination of the laser beam with the high-pressure liquid jet leads to a redistribution of the radiation intensity on the surface of the barrier.

Test processing was performed on AMr-2H, 12X17 plates with a thickness of 3.5 mm in the following modes: power - 300 W, pulse frequency - 75 Hz, blowing of the cut zone with compressed air at a pressure of 0.35 MPa, working feed rate - 12 mm/s. As a result, a normal edge with a roughness Ra of 3.2 μm, a thermally affected zone of about 1.2-1.5 mm was obtained. A detailed electron microscopic study proved the presence of individual phase transformations in the area adjacent to the edge, with a change in the size of the grains of the body of the sample. It was assumed that the laser beam can be fed into the jet both at the point of its contact with the surface and at an arbitrary point on the axis of the jet. Taking into account the considerations highlighted in [4], the reflection of the beam in the shell of the jet (at an angle of about 470 for a coherent beam with a wavelength of 1062 nm) will ensure the direction of the beam inside the shell of the jet. Structurally, it is quite simple to do, because the investigated LSK-400-5 complex allows for technological adjustment without significant complications.

When analyzing the patterns of destruction and the resulting openings, it was established that the process occurs in stages and is quasi-cyclic in nature. Cyclicity manifests itself on several harmonics and is determined both by the fluid flow conditions and by the frequency of laser pulses; practically do not depend on the structure of the processed material and the physical and mechanical properties of its components. When using a solid-state Nd: Yag laser with a wavelength of λ = 1062 nm, peak amplitudes occur at frequencies (0.2-0.25)nl and (2.4-3.5)nl, fig 1. At the same time, phenomena related to changes in the structure of the layer and its chemical composition occur in the surface layer of the workpiece, because at the moment of application of the radiation pulse, a liquid cavity with supersaturated steam appears on the surface, the dimensions of which change cyclically when the regimes of energy influence change.



a.

b.

Fig. 1. An ellipse-shaped hole obtained during steady fluid movement (a) and obtained when the flow regime is disturbed (b)

At the same time, the jet-radiation effect satisfactorily forms a profiled hole, the shape of which relatively fully corresponds to the profile of the nozzle, and also prevents the spread of thermal influence beyond the limits of the beam. At the same time, the more the mode of movement of the liquid corresponds to the laminar one, the better the quality of the obtained hole, the smaller the defects of the surface layers and the smaller the deviations from the expected shape.

3. CONCLUSION

So, the laser-jet cutting process is promising, highly efficient and versatile when processing a wide range of materials. The process is implemented according to various schemes of combining a laser beam with a jet of high-pressure liquid, and the proposed method of introducing the beam allows you to obtain the same effects as those declared by the world leader in the field of jet-laser technologies.

Laser-jet impact is an effective and efficient method of obtaining profile holes in the fillers of cellular panels and in the panels themselves, which is characterized by high productivity and allows obtaining holes without thermal and mechanical defects. The method can be used both for foil fillers and for metal panels made of stainless steel up to 1.5 mm thick.

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