



REMOVAL OF THE DEFECTIVE LAYER AND STRESSES HUBS DURING MICROPROCESSING OF ROLLED THIN SHEET SPECIMENS OF METAL CELLULAR PANELS

A.F. Salenko *

V.Y. Kholodnyi,

G.V. Gabuzian

Kremenchuk national university named after M.Ostrogradskiy, Kremenchug, Ukraine

Article history: Received 15 October 2015, Accepted 07 January 2016

Abstract

It is shown the problems of the influence of the perforation method of an aluminum-magnesium foil on its strength characteristics. Discussed concept of the research stand. It is given the results of numerical and natural experiments. Received recommendations of the selection of an optimum method for perforation manufacturing during processing of rolled thin sheet specimens of metal cellular panels.

Keywords: hole; perforation; cellular panels; water jet guided laser method.

INTRODUCTION

Rolled thin sheet specimens from aluminum (including AMh2-H), titanium (VT-15, VT-19) or stainless (12H17) alloys are widely used in the production of cellular panels in the aviation and space industry. Foil (with thickness 0,025-0,055 mm) is used for the manufacture of cellular sandwich panels aggregates; it is previously perforated with holes 0,05-0,18 mm and taugth in corrugated set with adhesive strips. Typically, processing of such workpieces is carried out mechanically (it is the most efficient and effective method of forming an array of holes for perforating to which there is no need of high requirements of precision); less holes are formed by laser beam.

In the first case there are material gaps that are random, in the second - defective layer is formed at the end; opening also has an arbitrary shape, and distribution of material degradation has unpredictable character. Sometimes one of sandwich elements is subjected to perforation - performing the holes in increments of 0.8-1.2 mm proportional to cellular filler walls (5x5 ... 12x12 mm).

It is viewed the possibility of holes performance with water jet guided laser method as such that precedes the occurrence of mechanical damage and thermal defects in the zone adjacent to treatment surface. The use of shaped water jet enables not only to get quality opening of some form, but also reduce the area of destruction and damage on the sheet workpiece, to eliminate gaps occurrence in places of openings that liquidate stress concentrators and areas with altered physical and mechanical properties.

Objective – definition of rational methods and techniques for processing conducting for most complete localization of the heat affected zone and reduction of stress concentrators action in the form of small holes on the mechanical properties of workpiece perforated with water jet guided laser method.

THE MATTER OF RESEARCH

It is known that water jet guided laser cutting is material processing mated with thermally-hydrodynamic flow of defined form, resulting of which is that an obstacle (treated surface) consistently takes editable shock hydrodynamic and thermal load. The alternation of these treatment phases is every time when after the laser radiation pulse surface barriers, which contact with the stream, in the area with the greatest velocity gradient of flow immediately overheated and melted with the formation cavities of supersaturated steam; in the pause between pulses these cavities merge in the flow, and shock wave is spreading on surface, while intensive cooling of influence zone.

The temperature in the cutting zone from action by the laser pulse [3] is:

$$T(x, y, z, t) = \frac{P}{\pi^2 \rho c} \int_0^l \left(\frac{e^{-\frac{(x-v(t-\tau))^2}{4a\tau+A^2}} \frac{y^2}{4a\tau+B^2}}}{[(4a\tau+A^2)(4a\tau+B^2)a\tau]^{1/2}} \right) \cdot \left[e^{-\frac{z^2}{4a\tau}} - h(\pi a \tau)^{1/2} \exp\left(-\frac{z}{2(a\tau)^{1/2}} + h(a\tau)^{1/2}\right) \cdot e^{hz+h^2 a \tau} \right] d\tau \quad (1)$$

where ρ , c , λ – density, specific heat and thermal conductivity of the material respectively; $a = \frac{\lambda}{c\rho}$ – a heat

capacity of the material; h – coefficient of heat transfer from the surface; A and B – larger and smaller semi-axis of elliptical beam; $P = \pi q AB$ – power of the laser emitter, and the action of liquid (refrigerant) take into account with

the objective of boundary conditions

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

$$\lambda \frac{dT}{dz}\Big|_{z=0} = \alpha(T)(T - T_p);$$

$T(x, y, z, t) = T_0$ at the approximation of the growth heat coefficient with addition of type

$$h(T) = h_m \exp\left(-\frac{(T - T_m)^2}{\Delta T^2}\right) \quad (\text{in accordance with [4]}),$$

which in the performance of numerical solution of equation (1), give a sharp decrease in temperature zones in place a supply of liquid which is cooled. Depending on the cost of the cooler and effectiveness of heat removal, the temperature fields difference could be material.

If we assume that the radiation power W is distributed evenly on some treated surface and radiation arrives on a normal, then during the time δt energy $W\delta t$ will come to the surface. For the length of the formed groove S amount of evaporated material will be Sbl . Based on the law of energy savings it can be written $S\rho bl \cdot h = W\delta t$, where h – the amount of heat required to evaporate a unit mass of material. Transforming this expression and assuming that $\delta t \rightarrow 0$, will have the groove growth rate in the form

$$\frac{ds}{dt} = \frac{1}{\rho} \frac{W}{blh}.$$

The last equation proves that for any material the marginal rate of grooves increase is proportional to the density of energy release W/A . Then the grooves length

$$\text{in the arbitrary time } t \text{ will be } l(t) = \frac{E(t)}{h\rho Sb} \int_0^t W dt, \text{ where } (t)$$

– total energy released by the source in time $(0, t)$.

So, limiting evaporation mode the grooves size depends on the total energy that comes to the surface. On the other hand, there is some transfer of energy deep into the material due to thermal conductivity. This phenomenon leads to the formation of destructive layer - the layer with altered physical and mechanical properties. The problem of phase separation boundary movement taking into account thermal conductivity is known as the Stefan problem. Assuming that the heat is distributed by the normal to the surface, will have a one-dimensional non-stationary heat equation

$$\frac{\partial^2 T}{\partial z^2} = \frac{1}{D} \cdot \frac{\partial T}{\partial t}, \text{ for the temperature inside the material } T(z,$$

$t)$ with the boundary conditions on the moving border $z = l(t)$ and on the back of the workpiece.

Here $D = \frac{K}{\rho c}$ – thermal diffusivity, K, ρ, c – thermal conductivity, density and specific heat respectively.

Neglecting the influence of the thermal conductivity of the material, equations to determine the dimensionless velocity of the evaporation border depending on dimensionless time will look like:

$$\frac{d\xi}{d\tau} = \left[1 + \varepsilon \left\{ \frac{1}{2} \operatorname{erfc}\left(\frac{\tau^{1/2}}{2}\right) - \frac{1}{\pi\tau^{1/2}} e^{-\frac{\tau}{4}} \right\} \right] \times$$

$$\times \frac{2}{\pi} \left\{ 1 + \frac{\varepsilon}{\pi\tau^{1/2}} \right\} \arcsin \left\{ \left(1 - \frac{\pi\varepsilon^2}{4\tau} \right)^{1/2} \right\} \quad (2)$$

Solving this equation allows us to calculate the dynamics and assess the grooves shape after impact of pulsed laser beam and define the limits of spread material destruction, that determine the thickness of the layer with altered physical and mechanical properties. At this closing of the steam-gas cavity under the bath of melt leads to hydrodynamic shock. The pressure at the moment of impact of the jet on the bath melt surface for fluid which is compressed, at impact is

$$p = \frac{\rho \cdot \dot{z}_0(t)c}{1 + \sqrt{\frac{\rho_1 \cdot E(1-\mu)}{(1+\mu)(1-2\mu)}}}, \quad (3)$$

where ρ_1 – density of jet; E, μ – properties of the liquid jet.

Under the influence of the fast jet to melt there is its almost instant cooling at a rate that approximates the speed of sound in the material. Jet energy is spent for heat removal from the melt zone, for the deformation of the micro volume and on the phenomenon in the displacement area on the edge of the workpiece and bath of melt. Having accepted that additional loss of kinetic energy caused by exposure shift is G , the balance of power will be:

$$\frac{1}{2} m_c \cdot \dot{z}_0^2 - E + G = \frac{1}{2} m_c \cdot \dot{z}^2 + \frac{1}{2} m_0 \cdot \dot{z}^2, \quad (1)$$

where \dot{z} – velocity after the destruction of the material, E – wasted energy determined by the difference of kinetic energy of the jet before and after the moment of contact,

$$E = \frac{1}{2} \left(\frac{m_0}{m_0 + m_c} \right) m_c \cdot \dot{z}_0^2,$$

where m_c – weight of the jet by nozzle edge; m_0 – mass of the destroyed material.

Fig. 1 shows the results of a calculation spreading zone of thermal destruction for the test materials under the laser and water jet guided laser impact, of which it is evident that at the action of the fluid flow there is no significant growth in the heat affected zone and active temperature increase doesn't occur.

Thus, it is possible action localization of high-energetic flow in a small field with simultaneous formation of the destruction hole, for example, the hole with diameter D . At the same time changing the terms of the combination of a laser beam with a jet of fluid of high pressure leads to a redistribution of the radiation intensity surface barrier, Fig. 2. However, the thermal load the surface remains localized, proving the the possibility of providing higher physical and mechanical properties of the treated material in comparison with traditional technologies.

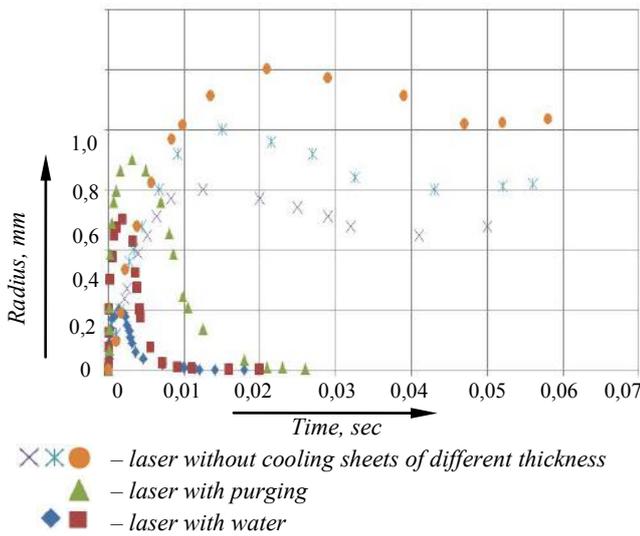


Fig. 1. Results of a calculation spreading zone of thermal destruction for the test materials under the laser and water jet guided laser impact

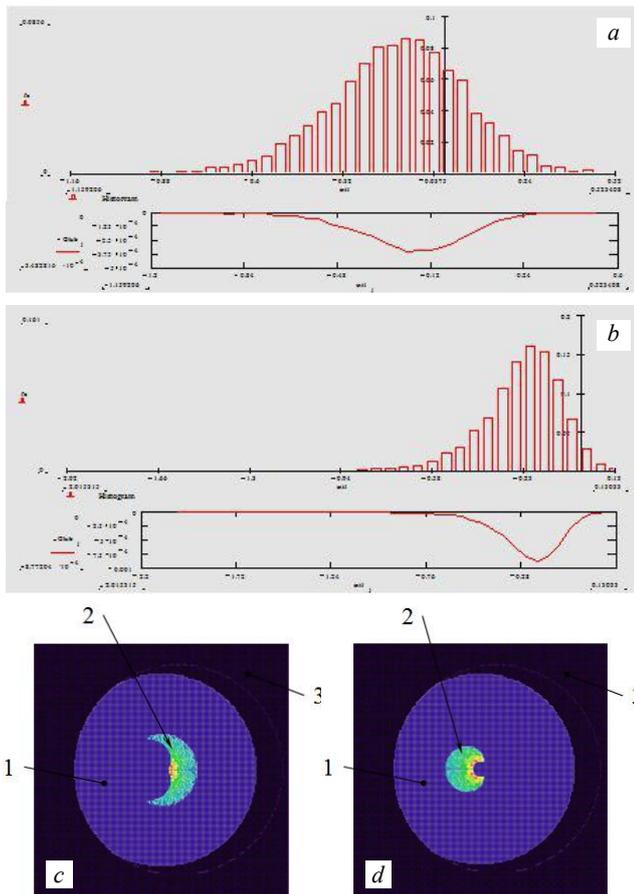


Fig.2. Histograms and aligned curves of the emission intensity in the spot on the treated surface. The axis of the laser relative to the axis of the nozzle is offset by the value $0,1D_c$.

Also, the radiation intensity distribution on a flat surface at leakage of jet diameter of 2.0 mm at a misalignment of the beam and jet in 0.8 mm to cut in the shape of a perfect circle

a – water jet guided laser impact; b– laser treatment without fluid flow; c– the distance from the nozzle edge to the barrier of 5 mm; d– 10 mm; 1 – reflection of the laser beam passing through the jet without the breakpoint; 2 – reflection of beam from the tapered portion of the nozzle and border "water-air"; 3 – the surface of the workpiece

Resulted studies have shown that increasing the pressure of fluid supply leads to a reduction of influence zone, but at the same time (Fig. 1) decreases the process productivity. At the same time precision combination of beam with jet axis considerably affects on the pictures of thermal effect on the surface: the difference from the ideal case leads to distortion of hypothetical histogram of distribution of the radiation intensity and to distortion of the hole firmware (Fig. 2, a).

Influence of geometric parameters of the jet stream and the conditions of the introduction of the laser beam into the jet stream on the parameters of the resulting hole in the sheet material thickness of 0.05-2.5 mm was evaluated using a special laboratory equipment, which allowed us to obtain a picture of the intensity distribution of the radiation (Fig. 2, b) and establish a functional conditioning of fields of intensity of irradiation by modes of fluid flow, nozzle profile, the deviation of the corresponding axes of the nozzle and optical system of the laser.

For obtaining pictures of the intensity distribution was used a laser light source with a nominal diameter of beam 1.2 mm (100 mW, 532 nm). Liquid jet was formed with an cap with outlet section diameter 2 mm of round, rectangular and oval form. The magnitude of the radiation was fixed by a photoresistor FSD-1. Data logging experiment was carried out with ADC m-DAQ. In studies L_{bi} distance from the end of the nozzle to the working surface varied in the range of 0,05 – 48,0 mm and a pitch of 1,0 mm, the pressure of the fluid before the cap – 0,5 MPa.

It was found that increasing the distance from the nozzle exit to the obstacle leads to equalization irregularities but further increase leads to a drop in the intensity of the surface irradiation. By changing the distance L_{bi} , we set the intensity distribution of radiation and received a number of diagrams of the heating surface temperatures (in dimensionless form) depending on the parameter $\Phi = \frac{W_i}{d_c}$,

W_i – displacement of the point of focusing on the confuser surface. It has been found that such displacement is able to cause the heating surface for area of direct application of the laser beam while leveling the radiation intensity in the central section.

Thus, the jet stream can not only cause intense cooling of the surface, but also to redistribute the radiation area greater than the area of the caustic on confuser. At the same time there is a certain distance between the nozzle exit and the surface, at which it is achieved the maximum intensity alignment with minimal loss of radiation power.

Since such a difference may lead to changes in the expected profile of the holes, it was conducted studies of form and precision in aluminum foil on installation LCS-400-5; treatment was performed in the following modes: flow pressure – 5.0 – 60.0 MPa, the pulse repetition frequency – 50 Hz, the holes formed by a single pulse or series during a 0,15-0,25 sec.

The resulting samples of holes have a shape corresponding to the nozzle channel. It was found that the achievement of a certain quality of edges of the hole is possible with changing in flow rate.

Depending on the required hole diameter D_0 and its shape, material grade and workpiece thickness h_z , the number of pulses varies. Thus, in the processing of test specimens (AlMg and 12H17) was set (Fig. 3a), that for the foil thickness of 25-55 microns opening can be obtained by a single pulse in the shortest time (is not greater than 0.05

sec.). Increasing the orifice diameter D_0 , increasing the thickness of workpiece requires a corresponding increase in processing time (number of pulses), which can be up to 2,0 sec. Thus further increase in the processing time only impairs the quality of the hole. Application of larger diameter nozzles is impractical because there is a significant form deviation of hole from the shape of the jet stream (Fig. 3, b). Comparison of the results shows that the round shape of the hole is most easily attainable; in the blank workpieces such openings are obtained to a diameter of 0,8 mm while reducing the accuracy of forms reproduction to 0,95; oval or square openings are obtained satisfying in form up to 0,25 mm. A further increase in size leads to a significant reduction of accuracy - on the average to 0,75 mm and less.

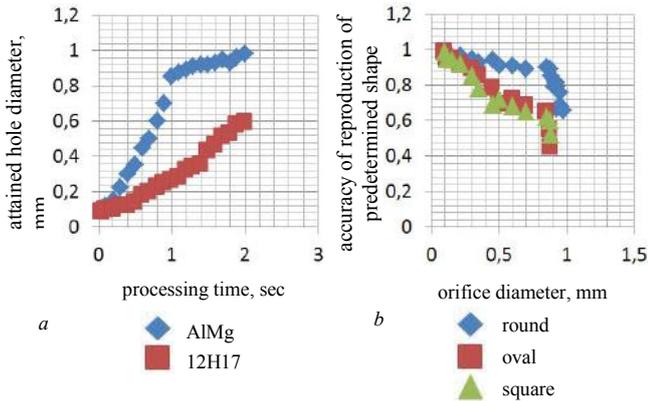


Fig.3. Achievable hole diameters depending on the shape of the nozzle edge: a – during processing time, sec; b – accuracy of reproduction of predetermined shape

However, visual assessment of the quality of holes form unfortunately does not allow draw a conclusion about the degree of deterioration of the physic-mechanical properties of a perforated sheet, in particular, the decrease in its tensile strength and high cycle fatigue. Observed defects in comparison to those, obtained by mechanical punching, have been eliminated, but the effects of thermal loading surface (Fig. 4, b), especially of thin aluminum foil, may have a greater impact on the strength properties than the presence of stress concentrators near holes in the form of breaks, clearly visible in Fig. 4, a.

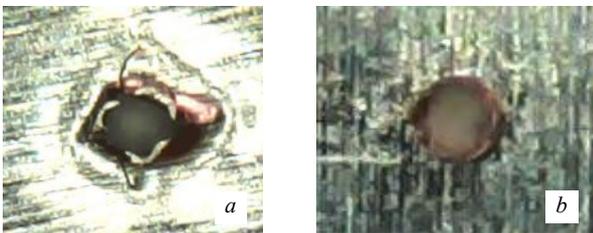


Fig.4. Samples of holes when performing perforation by mechanical (a) water jet guided laser (b) methods (on the outlet side of the tool and the beam, respectively)

To evaluate the effectiveness of perforating the foil with water jet guided laser method, in comparison with other methods, there were carried mechanical tests on specimens obtained with the mechanical needling (Fig. 4, a), the water jet guided laser method (Fig. 4,b) and laser needling with a purge of holes with diameter 0,08-0,1 mm.

The studies were conducted using a universal testing machine UME-10, the strain gauge KELI DEG and were recorded by the ADC m-DAQ. In order to record the results of the measurements was used ADC m-DAQ with a signal amplifier, which wiring diagram is shown in Fig. 5.

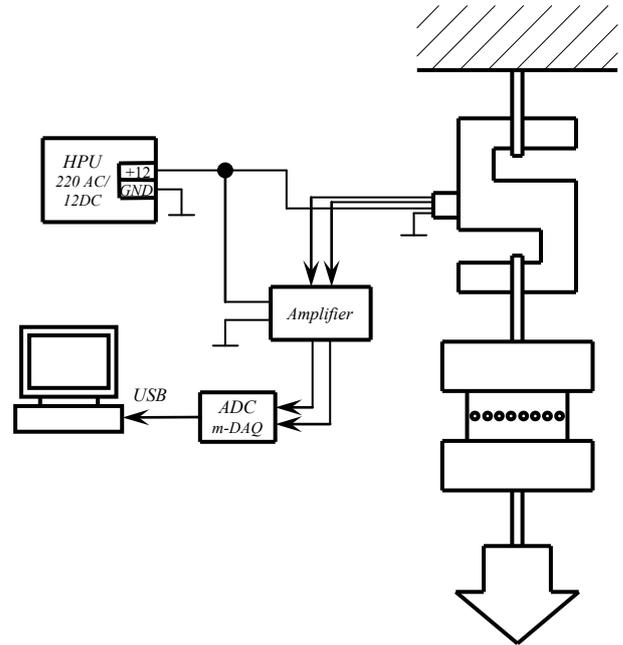


Fig.5. Schematic diagram of the research stand to determine the mechanical properties of the specimens

There were used specimens from the magnesium-aluminum foil in 55 microns in size 30×35 mm in studies (Fig. 6). On each of the specimens, using various processing techniques, there were made holes approximately equal in diameter and arranged at a constant pitch $t=5.0$ mm in the form of perforating line which is perpendicular to the line of application of tensile force of testing machine. Loading of the specimen was performed with the filing of 100 mm/min, deformation and, accordingly, arising stress was evaluated by the time series obtained from m-DAQ.

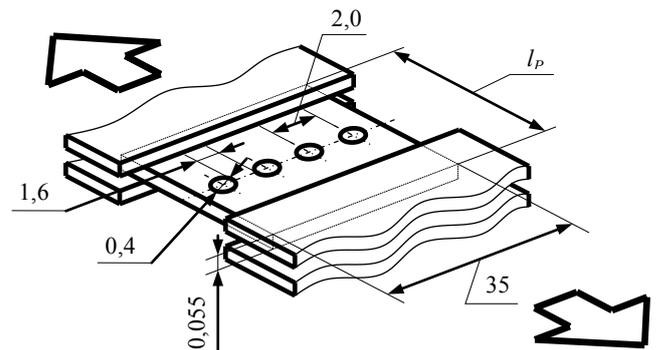


Fig.6. Schematic representation of the fastening of the test specimen in a tensile test, indicating its geometrical dimensions

The research results are shown in Fig. 7. The specimens were subjected with static loads with perforations applied by five different methods, namely: water jet guided laser, mechanical piercing, laser through a water layer, laser with a purging, laser without purging.

Analysis of the results of experiments (namely,

dependence the magnitude appended to the specimen load from the loading time of the sample prior to its destruction by perforating line) showed that the specimen from aluminum-magnesium foil, on the condition forming therein perforation using a water jet guided laser processing method, withstands loads on elongation larger for 22% in comparison with the specimens having the perforation lines formed by mechanical method, and by 35-40% - in other ways.

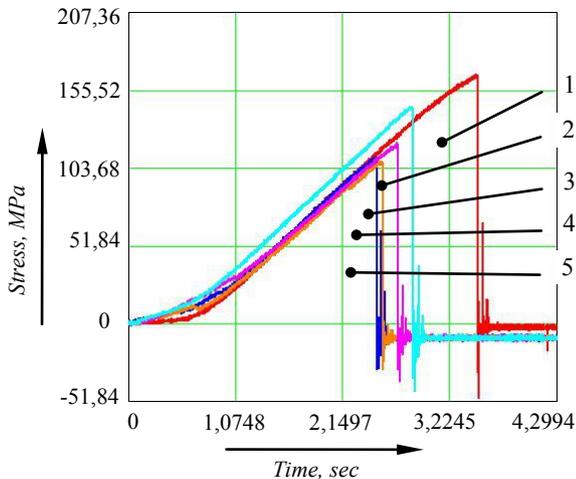


Fig.7. The results of rupture experiments on specimens from AlMg foil with thick in 55 microns of applied perforation under static loading

Methods of perforations: 1 - water jet guided laser; 2 - mechanical piercing; 3 - laser through a water layer; 4 - laser with a purging; 5 - laser without purging

At this loading duration of the specimen (from the beginning of the growth therein of internal stress to fracture) much higher than the similar characteristics of other specimens (for individual specimens – for one third), indicating almost constant flow of the specimen before and after perforation. Thus, the elongation of the perforated specimen was 14 %. While tensile strength reducing less than 18 MPa and made 132 MPa.

The results were used to perforate the inner filler for cellular panels (8, a, b), which is a sheet which was punched and applied the adhesive strips with the width of 2.5-2.7 mm, allowing to get cellular system after sheet corrugating. (Fig. 8, c). Use the method of holes automatically receiving with water jet guided laser method allowed to exclude the defect (as seen in Figure 8, b, where the holes been put in the adhesive strip), and reduce the cost of the panel while increasing its mechanical strength.

Thus, a slight decrease in the mechanical properties of the test specimens with holes in the form of perforations obtained by water jet guided laser processing method, in comparison to mechanical perforation traditionally used in industry, is caused by localized defective area and the absence of other stress concentrators in the application of water jet guided laser needling technique.

CONCLUSION

On the basis of conducted researches the following conclusions:

1. In case of use of sheet blanks during micromachining, namely in the manufacture of holes of various configurations, a water jet guided laser method processing of material, it is confirmed the possibility of reducing the defect layer and stress concentrators.

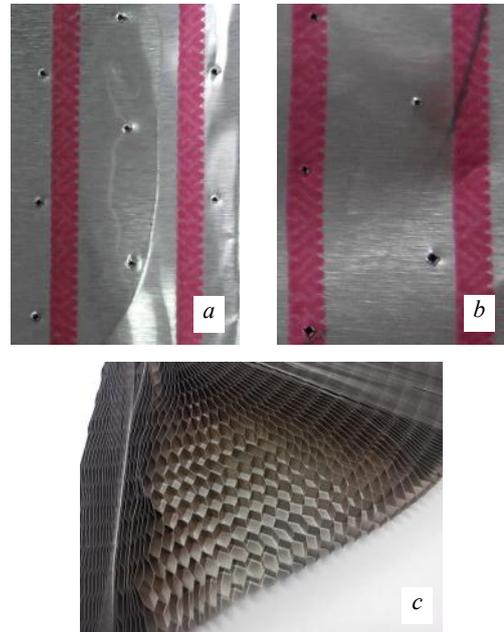


Fig.8. Filler of cellular panels (a, b) and ready-made corrugated set (c): a – produced by the conventional mechanical piercing; b – using the proposed method

2. In order to achieve the desired quality of the edges of the produced holes during design and commissioning of equipment it is mandatory to consider such options of water jet guided laser method processing of material, as the length of the liquid jet and permissible misalignment and crossing axes in the system "beam - jet."

3. Using the method of water jet guided laser method processing of materials can improve the strength of the finished product.

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