

SPECIAL EQUIPMENT AND TECHNOLOGIES IN AVIATION PRODUCTION

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National Aerospace University named after M. Ye. Zhukovsky
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SPECIAL EQUIPMENT AND TECHNOLOGIES IN AVIATION PRODUCTION

Study guide

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Розглянуто технологію виготовлення металевих і неметалевих стільникових конструкцій сучасних літаків і вертольотів. Описано основні етапи технології виготовлення стільникових пакетів, підготовки до склеювання, збирання хвостового відсіку лопаті вертольота, види дефектів і засоби неруйнівного контролю стільникових конструкцій.

Викладено особливості листового штампування важкодеформівних матеріалів, характерні ознаки процесу динамічного штампування на молотах із радіаційним нагріванням і штампування, поєднаного з високотемпературним термообробленням. Проаналізовано технологічні можливості сучасного високопродуктивного обладнання з використанням концентрованих потоків енергії. Наведено технологічні схеми формоутворення з використанням термофіксації й ізотермічного штампування, а також у стані надпластичності й дифузійного зварювання.

Для студентів, які вивчають дисципліни, пов'язані з літако- і вертольотобудуванням, виробництвом літальних апаратів, а також із системами автоматизованого проектування.

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The technology of manufacturing metal and nonmetallic honeycomb constructions of modern aircraft and helicopters is considered. The main stages of the technology of manufacturing cell packets, preparing for gluing, assembling the casing of a helicopter blade, defects and the means of non-destructive control of honeycomb constructions are described.

The features of sheet punching of hard-to-deform materials, features of the process of dynamic punching on the hammers with radiation heat and punching combined with high-temperature thermal treatment are described. The technological possibilities of modern high-performance equipment with the use of concentrated energy flows are analyzed. The technological graphs of forming with the use of heat-fixation and isothermal punching, including the state of superplasticity and diffusion welding are given.

The book is intended for students of specialties related to aircraft and helicopter engineering, aircraft production, and automated design systems.

Fig. 59. Tables 5. Bibliogr.: 14 names

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INTRODUCTION

Honeycomb constructions are widely used in modern aircraft construction. In aircraft of the new generation more than 30% of the area of the fuselage, wings, tail fins and other parts of the aircraft are made of honeycomb structures, consisting of two sheets of sheathing, with a honeycomb filler in-between. The unique example of the design with honeycomb filler made of aluminum foil is the doors of the rear cargo hatch of An-124 «Ruslan» aircraft.

The use of three-layer panels with fillers in the designs of aircraft allows the following:

- reducing mass and labor intensity in comparison with riveted constructions by 10 ... 30%;
- reducing the number of parts in structures and increase the rigidity by three to four times;
- improving the thermal insulation properties of panels;
- increasing smoothness of streamlined surfaces.

The level of technology of punching production of aircraft manufacturing plants is largely determined by the materials used in manufactured products. The tendency to increase the number of sheets of high-strength steels and titanium alloys in new products, as well as the development of new brands of high-strength and, as a rule, non-plastic materials, explains the need to re-equip production with new, modern, high-performance equipment using concentrated energy beams.

One of the promising directions for improving the technology of sheet punching in the manufacture of thin-walled parts in the form of membranes of titanium alloys in the conditions of small and medium-scale production is the use of superplastic forming of sheet blanks.

Industrial development of the superplastic formation allows us to obtain thin-walled bulk products of complex configuration, their manufacture using traditional processes of sheet processing is unprofitable or practically impossible.

1 TECHNOLOGY FOR THE MANUFACTURE OF METAL HONEYCOMB CONSTRUCTIONS

1.1 Structural and technological features of metal honeycomb constructions

The honeycomb structure in general consists of two panels 1, connected to the honeycomb filler 2, using layers of glue and surrounded by perimeter elements of the frame 3 (Figure 1.1).

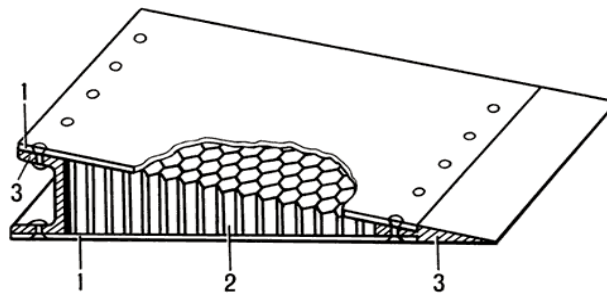


Figure 1.1 – Typical constructive elements of a honeycomb design

Three-layer constructions with honeycomb filler and metal sheathing are used in the design of the nose and tail parts of the wing and fins, flaps, interceptors, brake shields, servo-compensators, trimers, ailerons, rudders, hatches, engine nacelle panels, landing gear fairing, tail compartments of helicopter blades (Table 1.1).

Table 1.1 – Typical variants of honeycomb constructions with aluminum alloys

Form of surface	Typical cross-sections	Installation areas
Flat, double or single curvature		Wing panels, stabilizer, tail fins; hatches, fairing
Plane and linear		Tips of ailerons, flaps, rudders; helicopter blade tail compartments
Single curvature		Interceptors, brake shields
Flat, single curvature		Floor panels, hatches
Linear		Elephants, flaps, trimers

Adhesive three-layer structures with honeycomb filler and metal sheathing provide the necessary rigidity of aggregates under bending loads, fatigue strength, compression strength and significant savings in the mass of aviation equipment products. Adhesive honeycomb structures also perform special functions as follows: sound-proof, heat-shielding, aerodynamic (smoothness of the sheath), decorative.

The following materials are used for the manufacture of metal honeycomb structures:

- foil of aluminum AMg2-N in thickness from 0.03 to 0.05 mm for making honeycomb filler;
- sheet duralumin D16T in thickness from 1.0 to 2.5 mm for sheathing of the honeycomb structure;
- phenolic-rubber glue VK-25 for the manufacture of honeycomb packages;
- adhesive VK-32-200 or VK-36 in the form of a glue film in combination with a liquid adhesive for connection of sheathing and elements of a frame with a honeycomb filler;
- Flexible Film VKV-3 for connecting a honeycomb filler with frame elements.

The strength of the filler is largely determined by the size of the cells. The smaller the cell, the higher the strength of the adhesive compound and the stability of the sheathing, working on compression before the formation of folds.

The most important in glutinous honeycomb structures is the connection of the sheathing with the filler. When choosing a glue it is necessary to take into account that the connection between the filler and the sheathing shall withstand approximately the same bias voltage as the filler.

When designing the design it shall be taken into account the direction of the strips of foil filler. With increasing loads along the bonding area of the cells, the strength of the connection at displacement increases by 1.5 times compared to the perpendicular direction.

An important technological feature of the production of honeycomb structures with the use of adhesive compounds is the need to remove gaseous by-products of the reaction of adhesives solidification. The presence of these products may result in the exfoliation or displacement of the filler under the influence of released gas. It is also necessary to take into account further corrosion of the filler as a result of chemical interaction with the gaseous products of the solidification reaction or with their condensates. To ensure the possibility of the release of gaseous by-products of the solidification reaction, a drain cell-filler is used.

The presence of perforation in the walls of honeycomb aggregates leads to the propagation of water in aggregates and reduces the operational reliability of honeycomb structures. Therefore, when designing such structures, it is ne-

cessary to provide structural and technological measures that exclude water entering the aggregates.

1.2 Technology of manufacturing metal honeycomb constructions

The process of assembly of a product with honeycomb filler has the following basic operations:

- development of honeycomb filler of necessary forms and sizes;
- preparation of sheaths, parts of a frame and honeycomb filler, application of glue;
- assembly and gluing of the honeycomb structure;
- gluing quality control.

The scheme for manufacturing a metal honeycomb structure is shown in Figure 1.2.

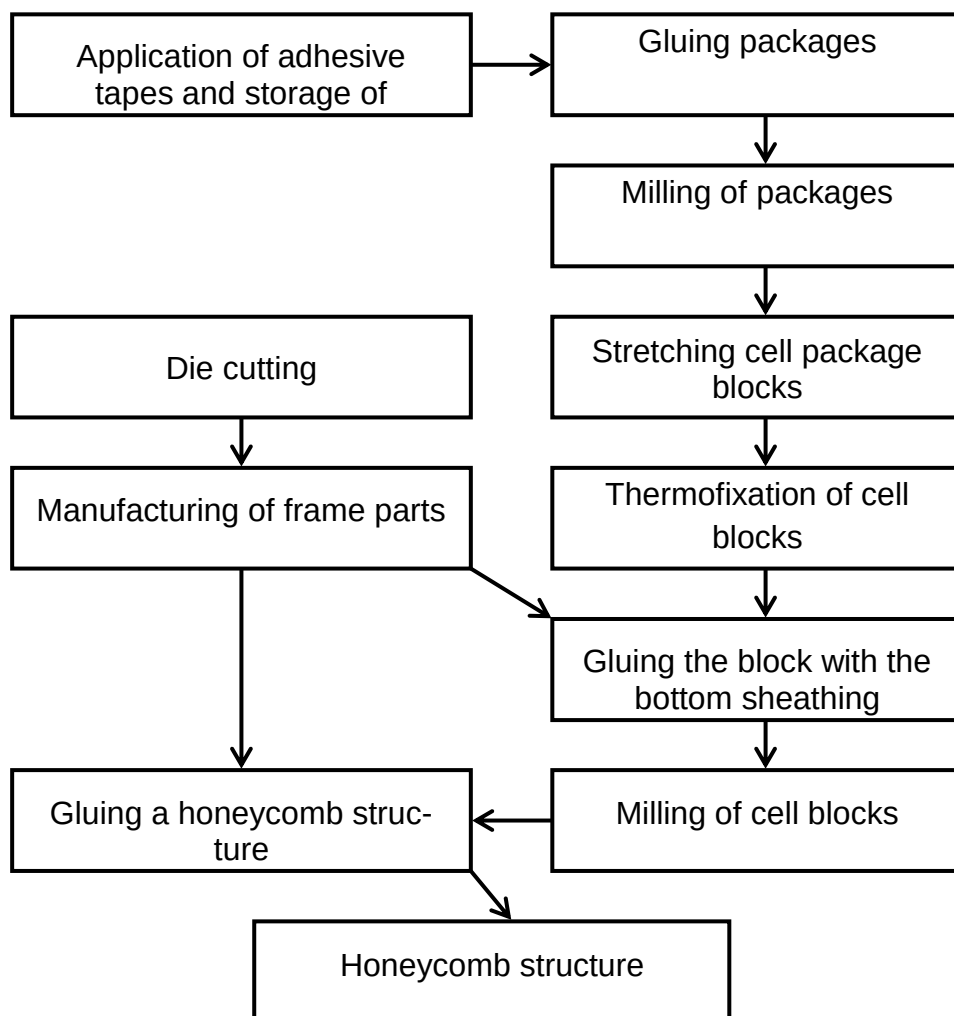


Figure 1.2 – Manufacturing scheme of the honeycomb structure

In aircraft engineering, two methods of manufacturing metal cells are used: consistent expansion and stretching [8].

The method of stretching honeycomb packages in the conditions of batch production is the most technological, as it allows us to mechanize and auto-

mate the production of cells, to simplify their mechanical processing. At the same time, the conditions of storage and transportation improve, which helps to centralize the production of honeycomb fillers.

Aluminum cell blocks are manufactured in specialized sections in the following typical technological sequence [12]:

- degreasing, drying, luminescent control of roll foil (installation of UV-2);
- edge trimming, double-layered adhesive strips, drying, package stacking (automatic installation of ASP-1000);
- cutting packages into blocks (tape machine LS-80-3);
- milling of packages in straight and curved contours (milling machine with CNC PP-7M);
- stretching of the honeycomb unit (automatic machine ARSB-2);
- milling of the ends of the cell block (specialized milling machine with CNC RFP-6);
- de-oiling the honeycomb unit in perchlorethylene (conveyor installation UOP-3);
- application of liquid glue on the end of honeycomb filler (installation UNK-2);
- application of film glue VK-3 on the end of honeycomb filler (installation of SPK-1);
- transmission of the cell block to the device for the general assembly of the honeycomb structure.

1.2.1 Foil de-oiling technology

Foil for the manufacture of honeycomb filler is supplied to aviation factories in rolls on a metal bush, the length of foil in a roll-off is 1500 m, the weight of a roll is 150 kg. Rolls are preserved and have oil contamination on the surface.

The roll foil is de-oiled in aqueous solutions of emulsifier OP-7 or OP-10 using ultrasound at the UFO-2 plant, which is used to rinse and dry the foil with subsequent luminescent degreasing quality control. The capacity of the degreasing bath is 800 liters, the wash basin is 460 liters.

To control the quality of degreasing foil, use a luminescent unit ULKO-3, which provides control of foil roll on both sides. All degreasing foil operations are performed in automatic mode: the speed of movement of the foil roll is 4 m / min, de-oiling in the bath – no less than 15 seconds, washing in the bath with clean running water – no less than 20 seconds, drying in the chamber – no less than 20 seconds.

In the process of roll foil movement, the quality control of de-oiling is performed by drip method on the basis of uniform dispersion of a drop of distilled water. Interoperable storage time of de-oiled foil is allowed not more than 10 days, prolonged storage – for three months, with careful packaging in a plastic bag with silica gel.

1.2.2 Technology of manufacturing honeycomb packages

The trimming of the edges of aluminum foil, longitudinal double-sided application of glue strips on both sides of the foil, drying of adhesive strips and the assembly of packages are carried out on the automatic unit ASP-1000. For application of glue strips leakage of a mixture of adhesives on a movable roll of foil is used (Figure 1.3).

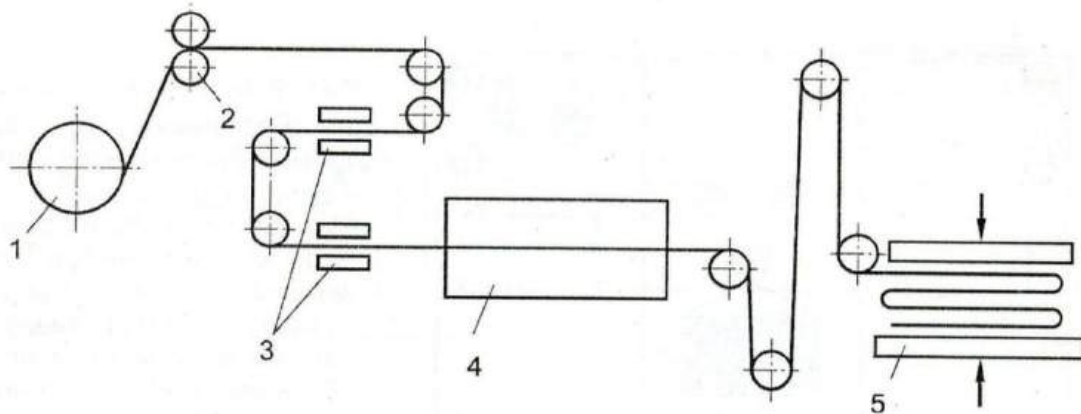


Figure 1.3 – Scheme for manufacturing a honeycomb packer package:
1 – roll holder; 2 – disk knives; 3 – glue; 4 – drying chamber; 5 – package layer

Automatic unit of ASP-1000 has the following nodes:

- a device for the installation and stretching of de-oiled roll foil 1000 mm wide;
- two glue pots with tanks of 3 liters for glue VK-25;
- needle and rubberized rollers for piercing in a roll of foil drainage holes with a diameter of 0,1 mm;
- a drying chamber with five temperature zones of heating of foil;
- a device for pulling and stretching a roll of foil with a chain drive and trimming knives;
- loop shaper – device for package assembly;
- press with a pull-out table.

The general view of the automatic unit ASP-1000 is shown in Figure 1.4.



Figure 1.4 – The general view of the automatic unit ASP-1000

Technical characteristics of the unit ASP-1000

Dimensions of the honeycomb package, mm:	
– width	990;
– height	400.
The largest quantity of letters in the package, pcs.	150
Thickness of foil, mm	0.03
Width of foil, mm	1000
Speed of moving foil, m/min	1.5 ... 3.0
Power consumption, kW	4.9
Overall dimensions, mm	12500x4090x2100
Weight, kg	24000.

The heat carrier of the drying chamber is tubular electric heaters laid in cast-iron plates, which are located on both sides of the roll of foil, which moves in the chamber. Set temperatures in five zones are maintained from 75 to 110 °C and provided automatically by an electronic potentiometer.

Drainage holes with a diameter of 0.1 mm are punctured by needles mounted on the needle roller when the foil passes between it and the protuberant roller. With further movement of the foil between the next row of rollers, the opening is extended. Drainage holes are placed between applied glue strips.

The cycle of assembly of one sheet of a package (one fold) from a roll is executed in the following technological sequence:

- the loop moves to the right, forming a loop on the roll; at the end of this movement, the loop includes limiters and clamps, and the loop shaper returns to its original position;
- the limiters and clamps are beyond packet assembly area;
- press presses the loop; limiters and clamps enter into the area of packing of the package over the executed fold;
- the press returns to the original position, the package until the formation of the next loop is held by the clamp.

The package shall be drawn up until a predetermined number of folds from the roll is in. A counter of the number of folds is set at the moment of their commencement from a roll of foil with applied adhesive strips.

For the manufacture of large-sized glued honeycomb packages of 460 mm (1500–2000 sheets) and up to 2500 mm in length, automatic unit ASP-2000 is used. Cross-application of glue strips on one side of the foil is carried out by the printed method (Figure 1.5), in addition, drying of adhesive strips and assembly of honeycomb packages are carried out.

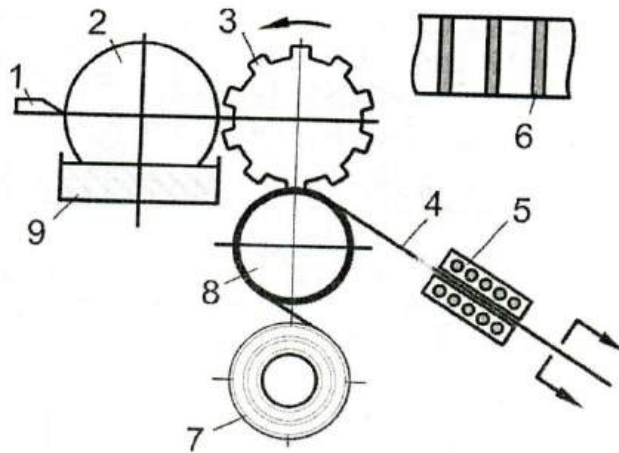


Figure 1.5 – The scheme of printing glue strips on the unit ASP-2000:

- 1 – knife; 2 – feed roller, 3 – adhesive roller, 4 – foil;
 5 – plate with electric heating; 6 – transverse adhesive strips on foil;
 7 – foil coil; 8 – clamping roller; 9 – glue bath

The width of the dried glue strips shall be 2.4 ± 0.3 mm, the thickness - from 0.005 to 0.012 mm. Offset adhesive strips are not allowed to exceed 0.2 mm. Control of width and thickness of adhesive strips is carried out every three months.

The adhesive of the honeycomb package is performed on a press with heating plates at a pressure of 1.5 ... 2.0 MPa and a temperature of 165 ± 5 °C for one hour. Then the package is cooled down under pressure to a temperature of 25 ... 30 °C.

Packages of honeycomb aggregates are cut in a compressed condition on the required number of dies on a tape machine LS-80-3 in a copier with an tolerance of 8 mm by perimeter at cutting speed of 900 m/min and minute feed of 300 to 600 mm/min.

Packages of honeycomb aggregates are molded in a compressed state on rectilinear and curvilinear contours on a machine tool with CNC PP-7M with the use of high-speed milling spindle. The absolute accuracy of the processing is no more than ± 0.05 mm.

1.2.3 Stretching the honeycomb package

Formation of cells of the correct hexagonal form by stretching the glued packages of honeycomb fillers is carried out on the automatic machine ARSB-2. The productivity of the machine is from 2 to 4 m²/min, the maximum dimensions of the stretched block of honeycomb aggregate are as follows: length – 6500, width – 1500, height – 300 mm.

The honeycomb package before stretching is fastened by pins to the upper and lower traverse's of the machine through the loops of the fabric of the 500mark. The fabric is glued to both sides of the honeycomb package with a rail with a groove. Grooved rails form loops throughout the package length (Figure 1.6).

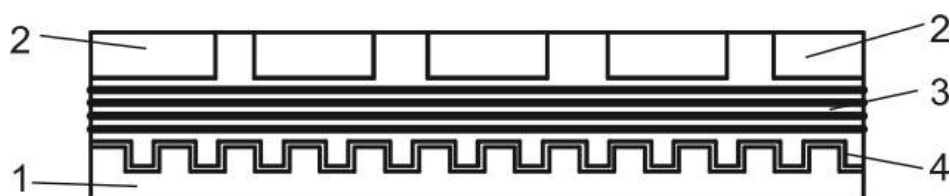


Figure 1.6 – Scheme of gluing a fabric to a bundle of honeycomb package:
1 – cradle; 2 – cargo; 3 – honeycomb package; 4 – tape

Figure 1.7 shows a cell block with a stuck-to-end fabric after stretching.



Figure 1.7 – Cell block after stretching

The dies of the cell filler of the tail unit of the blade are stretched on the automatic machine ARSB-1 (Figure 1.8).



Figure 1.8 – Stretching the honeycomb block of the tail unit of the blade

The degree of stretching of the cell block is checked by the number of hexagonal holes in the length of 200 mm: they must be 50 (+ 5, - 3). Snapped cells are manually threaded.

1.2.4 Milling the ends of the cell block

In honeycomb structures in the form of panels, units of mechanization of the wing of the aircraft and tail sections of the helicopter blade, it is necessary to process the faces of cell-fillers directly connected to the elements of the aerodynamic outline formed by the percentage surfaces. Such processing requires a special approach to the choice of cutting modes, methods of basing and fastening of dies, milling cutting schemes, design of cutting tools, dust removal tools and chips from the cutting zone [12].

Milling of the ends of the cell blocks is carried out on a special milling machine with CNC RFP-6. The machine tool is intended for processing of end faces of spatial forms of honeycomb plasticizers by longitudinal and transverse lines, and also for milling of blades at the ends of honeycomb aggregate. The CNC N55-2 device provides automatic tool change, correction of the equidistance of the trajectory, switching of the spindle rotational speed.

The layout of a special milling machine with CNC RFP-6 (Figure 1.9) allows us to handle the ends of the cell block at the same time at five coordinates:

- longitudinal movement of the portal;
- transversal movement of the carriage relative to the portal;
- vertical movement of the carriage relative to the portal;
- turning the carriage around the transverse axis at an angle of $\pm 30^\circ$ (according to the coordinates of **B**);
- turning the carriage with the milling head around the longitudinal axis at an angle of $\pm 135^\circ$ (at coordinate **A**).

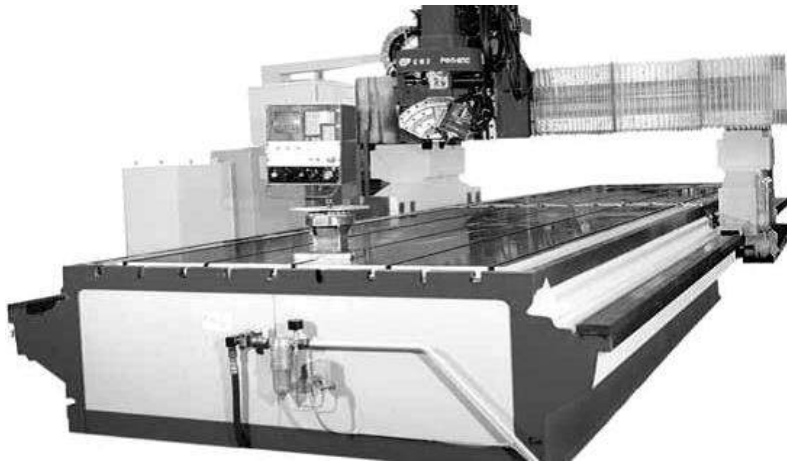


Figure 1.9 – Special machine with CNC RFP-6

The honeycomb filler on the ends is milled with special fungal cutters from high-speed steel with diameters from 12 to 70 mm. Before processing, the cell block is fixed on a production slab using a special adhesive – polyethylene glycol [12]. Approved cutting mode of the ends of the cell unit is as follows: the

frequency of rotation of the fungal cutter - 18000 1/min, minute feed - up to 3500 mm/min.

Technical characteristics of the milling machine with CNC RFP 6

Maximum displacement, mm:

- longitudinal X table	6500
- transverse Y carriage	1750
- vertical Z milling head	400

Maximum displacement, degrees:

- rotary carriage A .	± 30
- rotary carriage C	± 135

Spindle power, kW

7,0

Spindle rotation speed limits, 1/min

1 ... 18000

Limits of linear feeds, mm/min:

- for coordinates X, Y	7000
- for coordinate Z	3000

Circle feed limits, 1/min:

- for coordinate A	2
- for coordinate C	2

Discreteness of the displacement assignment, mm

0,001

Number of coordinates controlled simultaneously

5

Positioning accuracy with one-sided approach, mm:

- longitudinal X table	0,20
- transverse Y carriage	0,12
- vertical Z milling head	0,08

Overall dimensions of the machine, mm:

- length	10365
- width	4700
- height	3280

Machine weight, kg

29000

When processing the concave side of the end of the cell block are based on the plane of the technological plate, and the convex side - on the second technological carrier plate on the already processed concave surface (Figure 1.10, a).

In the milling scheme of the zigzag along the percentage lines (Figure 1.10, b), the depth of the cut Δ on the convex and concave portions of the cell filler does not exceed ± 0.04 mm.

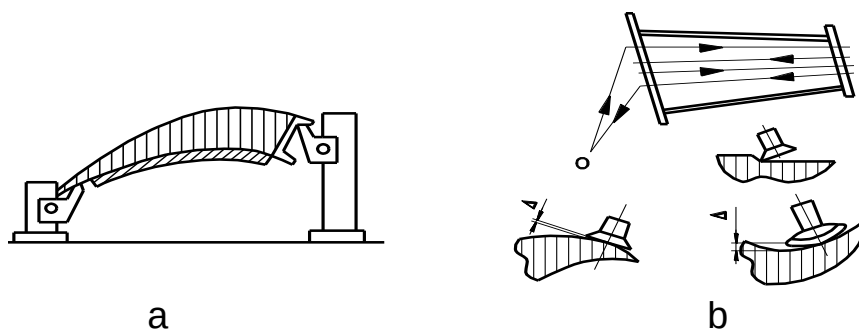


Figure 1.10 – Schemes of the base (a) and processing (b) the cell block

In accordance with the adopted scheme of the trajectory, "zigzag" calculates the step of the line of the instrument when performing two neighboring work tracks of the trajectory. The value of the step is determined by the tolerance on the height of the fin edges, which remain on the surface to be treated between adjacent working steps. In the general case of three-dimensional bulk processing, the cutting edge of the cutter moves on a surface with variable radius of curvature.

Then the step of the tool line when two neighboring working tracks of the trajectory are calculated, specifying the admittance on the edges:

$$A = \sqrt{\frac{8\Delta_{op}}{1/R - 1/\rho}}. \quad (1.1)$$

Usually, the following correlation of the processing error to the geometric parameters of the surface and the radius of the final fungal mill is accepted:
 $\Delta_{op} \approx 0,01R$ и $\Delta_{op} < (0,01..0,001)\rho$.

Figure 1.11 shows the base of the concave side of the cell block on the convex side of the technological carrier plate.

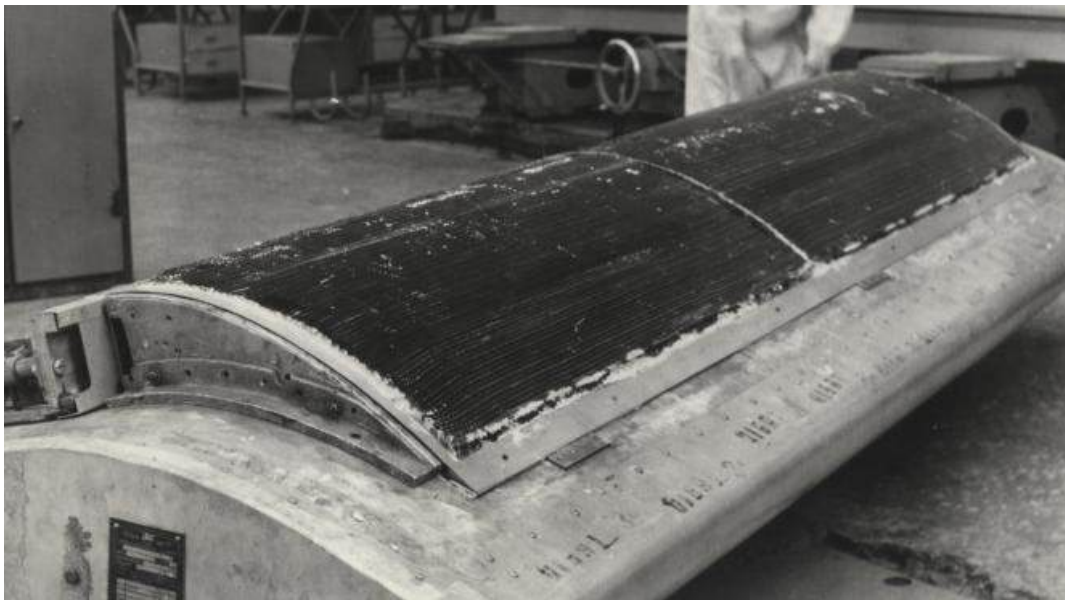


Figure 1.11 – Bonding of the concave side of the cell unit on the technological carrier plate

The processing of the concave surface of the honeycomb aggregate block and the manufacture of the technological carrier plate are carried out according to one control program, which ensures high precision of the base and manufacture of the honeycomb filler.

1.2.5 De-oiling of the cell block, applying glue on the ends of the cells

After machining, the cell blocks are de-oiled in a vapor and liquid perchlorethylene on a UOP-3 conveyor plant, the scheme of which is shown in Figure 1.12.

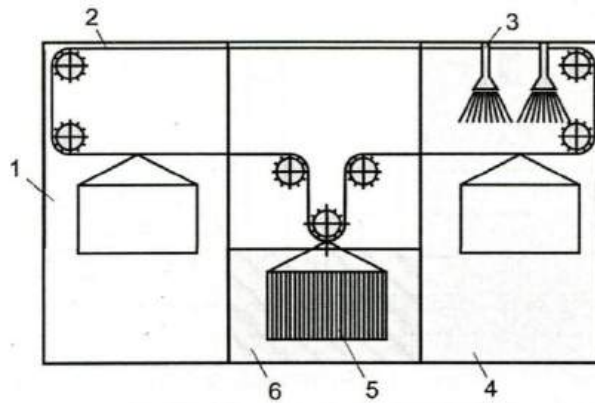


Figure 1.12 – Scheme of the unit for de-oiling the cell block:

- 1 – drying chamber; 2 – transport line; 3 – device for feeding gaseous perchloroethylene; 4 – steam cell de-oiling; 5 – honeycomb filler;
6 – de-oiling dipping camera

At the unit UPS-3, it is possible to de-oil the blocks of the honeycomb filler, the parts of the frame and the sheathing of aluminum alloys in the sizes up to 6500x2000x300 mm (the speed of the transport line is 3.5 m/min).

Liquid glue at the end of the cell blocks is applied on the UNC-2 unit. The scheme of this process is shown in Figure 1.13.

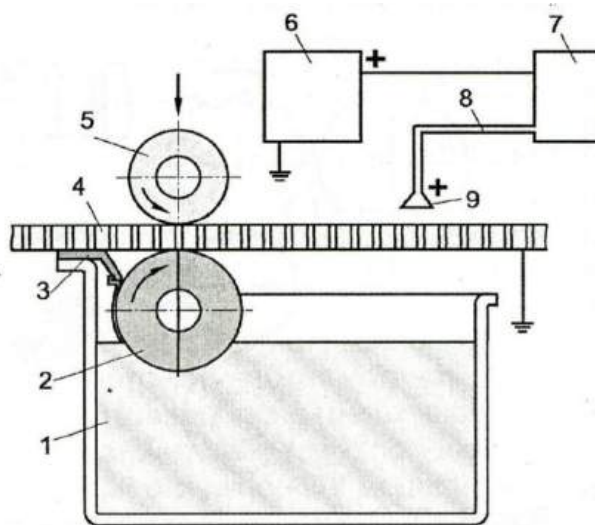


Figure 1.13 – Scheme of application of liquid glue on the ends of the cell blocks: 1 – bath with glue; 2 – adhesive roller; 3 – scraper; 4 – cell block; 5 – press roller; 6 – high voltage source; 7 – glue container; 8 – dispenser; 9 – centrifugal sprayer

When applying liquid glue, the ends of the cell block form pegs, which provide a reliable contact and a strong connection of the honeycomb filler with a sheath.

At the unit SPK-1 film adhesive VK-3 is rolled on the end of the cell-filler, as well as on the sheathing of honeycomb structures.

To exclude the wrinkling of the glue film before the plating, the honeycomb filler is straightened and fixed in the layout of the frame of the honeycomb structure (Figure 1.14).



Figure 1.14 – Fixing the honeycomb filler in the layout of the frame of the honeycomb structure

As an example, cell-based filler made of aluminum foil in the caudal compartment of a metal blade Mi-8 helicopter is shown.

1.3 Preparation of sheeting of honeycomb filler for gluing

Chemical treatment of the sheathing to ensure high adhesion by removing oils and other contaminants and forming a microporous layer on the surface is carried out in baths and chambers according to the scheme shown in Figure 1.15.

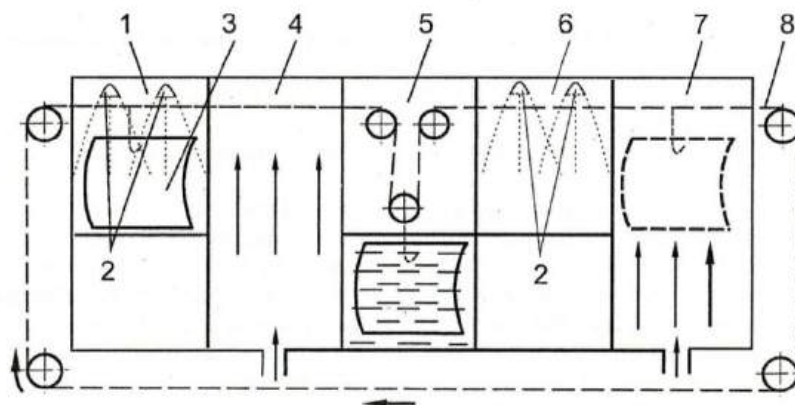


Figure 1.15 – The scheme of chemical processing of sheaths:
1 – de-oiling chamber; 2 – sprayer; 3 – sheathing; 4.7 – drying chamber;
5 – pickle bath; 6 – washing machine; 8 – conveyor

After preparation of the surface of the sheaths up to 1900×7200 mm are anodized in a bath VA-1 (Figure 1.16).

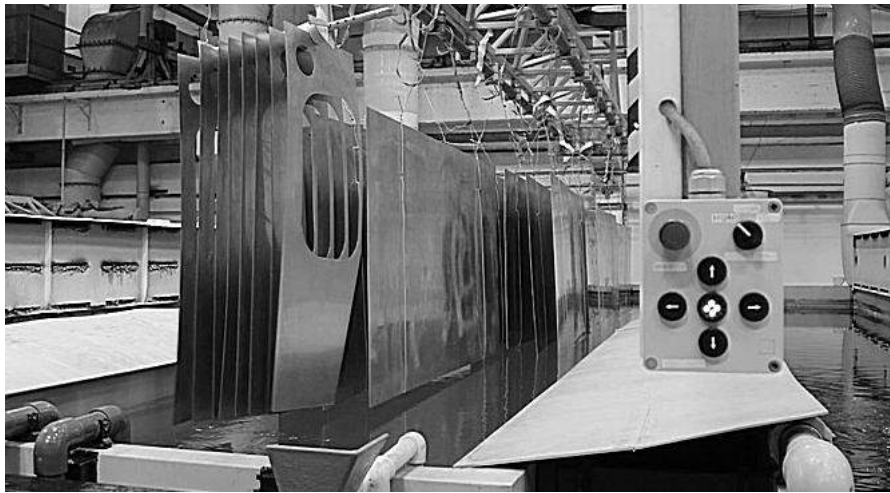


Figure 1.16 – Bath model VA-1 for anodising of sheaths

The thickness of the anode film with chromocyclic anodizing of the panels is 5 ... 8 μm , the productivity of the bath is from 15 m^2/h and above. After washing and drying with the help of the TPK-1 device, check the anodizing quality of the sheathing. Then the sheathing is covered with a protective soil of the mark SPM-102 in the electrostatic field of the unit UNG-1, which is covered with soil 80 ... 100 m^2 per square meter per hour (soil flow – 30 ... 60 g/m^2 , speed of spraying – from 0.5 ... 4 m/min). After solidifying the soil in the drying chamber, the quality of its application is controlled by the device LKD-1.

Recently, adhesive soils have been used increasingly, which not only protect the surface prepared for gluing, but also contribute to improving its wettability, spreading the glue, and also increasing the elasticity of the adhesive compound.

Sheets are covered with protective soil, have a film of glue applied in the thickness of 0.12 mm. The film is stored in a refrigerator and heated to room temperature in order to exclude moisture condensation on its surface, in accordance with the scheme shown in Figure 1.17.

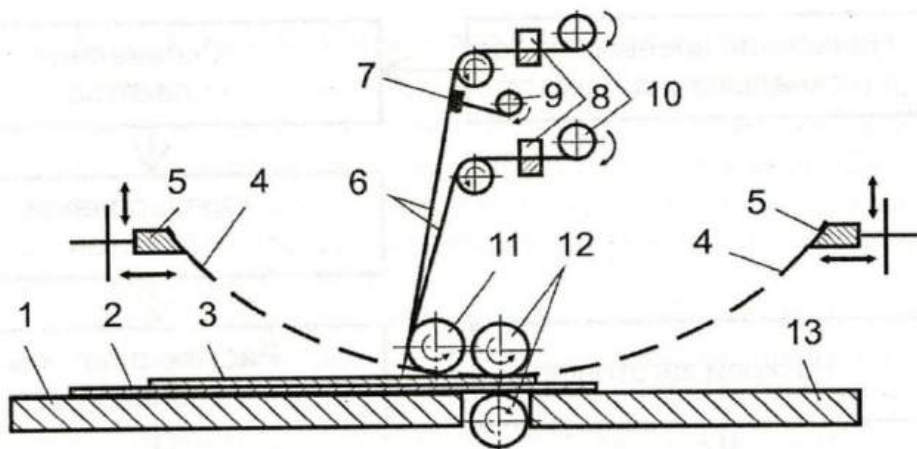


Figure 1.17 – Scheme of rolling adhesive film on the sheathing

Figure 1.17 shows the following markers: 1, 13 – the table of the machine; 2 – technological sheet; 3 – flat paneling; 4 – sheathing of single curvature; 5 – supporting device; 6 – adhesive film; 7 – disk knife; 8 – a device for wetting the glue film with acetone; 9 – roller; 10 – rolls of glue film; 11 – leveling roller; 12 – rollers for rolling adhesive film.

For rolling the film glues on sheaths and faces of honeycomb fillers machines SPK-1, SPK-2 and SPK-5 are used. Machine SPK-5 provides the speed of pouring adhesive film from 0.5 to 4 m/min on sheets of width up to 2100 mm and length up to 7200 mm.

1.4 Assembly of the tail unit of a helicopter blade

The tail unit of the helicopter blade is a typical metal structure with honeycomb filler made of aluminum foil Amg-2-H thickness of 0.03 mm (Figure 1.18).

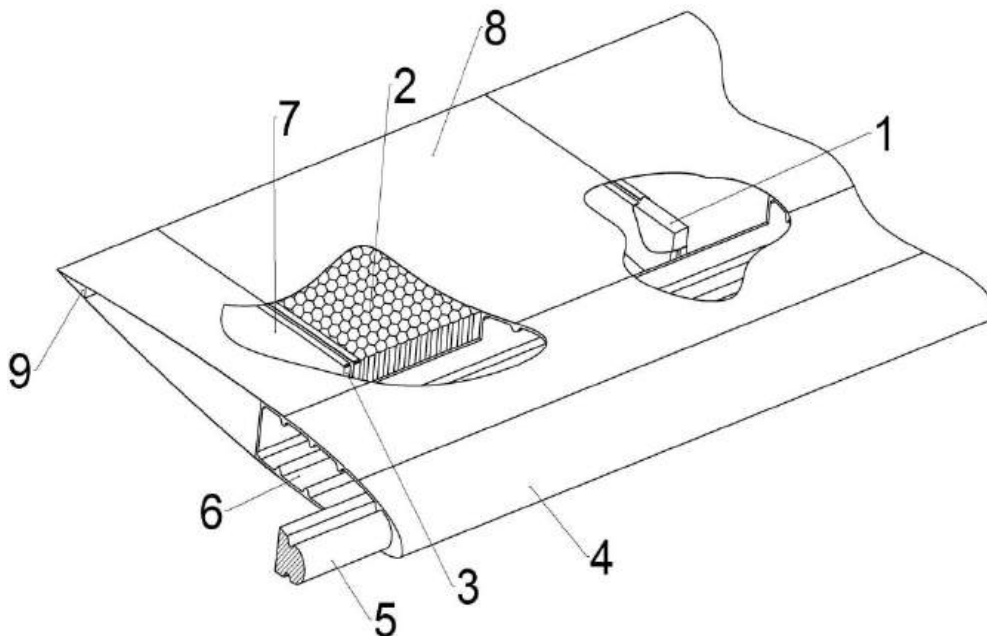


Figure 1.18 – Structural power scheme of a metal blade:

- 1 – bushing; 2 – honeycomb filler; 3 – rib latch; 4 – anti-freezing system;
- 5 – anti-flyer cargo; 6 – spar; 7 – rib; 8 – sheathing; 9 – tail stringer

Ribs are made of sheet D16AT-I 1.0 by cold stamping. In the places of gluing the ribs to the spangler, the wall of the rib is bent and represents a foot, which is glued to the spar.

The compartment has sheets D16AT-I 0,5, glued together with a honeycomb filler with two lateral ribs and a tail stinger.

The assembly of the metal caudal compartment of the helicopter blade is performed in a special device (Figure 1.19).

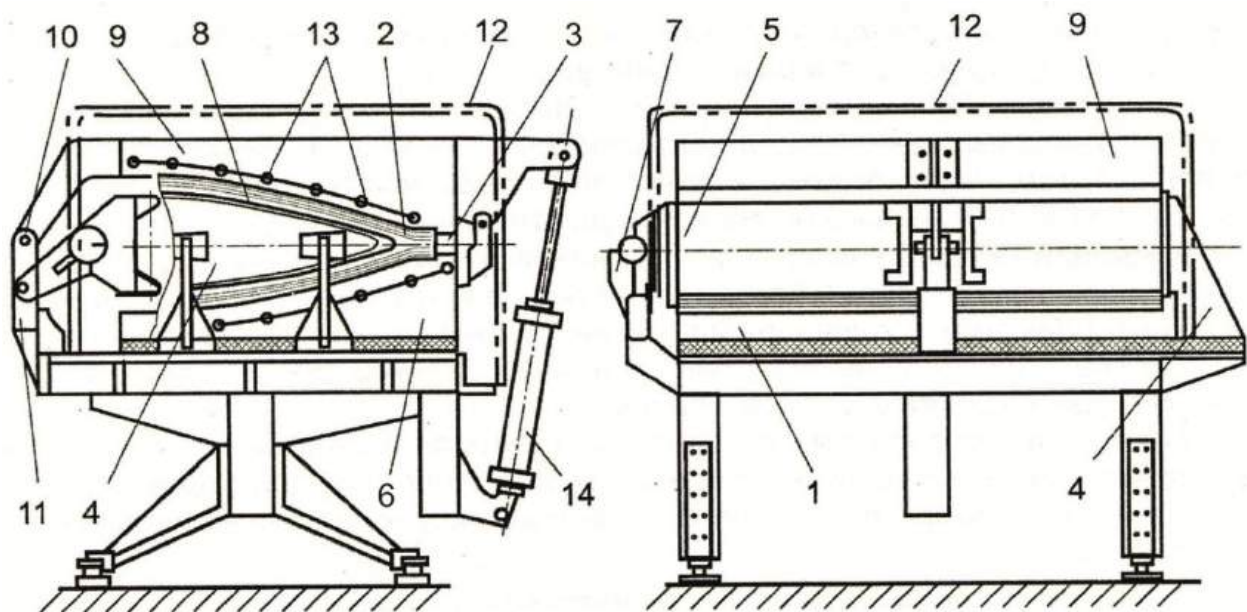


Figure 1.19 – Devices for the assembly of the tail unit of the blade

The assembly of the tail unit of the blade is performed in the following technological sequence [9]:

1. On the bottom plate 1 fix the layers of asbestos fabric 2, which set the tail stinger and sheaths of the tail section. Sheaths in the transverse direction are supported in the support plate 3, in the longitudinal - in the end plate 4.

2. In the cavity between the sheaths, install a cell block and ribs with pre-applied glue film.

3. The ribs and cell are pressed with a technological plate 5 to the plate 6, and the plate 5 is fixed to the working position by the latch 7.

4. Install a plate-cover 8 with layers of asbestos fabric and rubber.

5. Close the plate 9 and fix it with lock 10 in the plug 11.

6. Cover the device with a heat-insulating casing 12. Turn on the electric heater 13 of the upper and lower plates. During the polymerization of the glue, the heat-fixing mode is supported.

7. After the gluing process is completed, remove the heat-insulating casing 12, open the upper plate 9 with the help of the hydraulic cylinder 14, remove the plate-cover 8, and remove the clamping plate 5.

8. Take out the finished tail unit of the blade from the device.

9. Check the quality of gluing the tail section by using a mechanized UCN-4P with CNC, equipped with impedance-acoustic device IAD-3.

10. After the control, lay the edges of the compartment, seal the ends of the honeycomb filler with an epoxy resin or an elastomeric sealant.

Typically, reduction of the bond strength is due to poor fitting of the dimensions of the connecting elements. If in the areas of high-quality bonding, the holes cut the adhesive film and fit up close to the sheath, then in the wea-

kened areas between the cell block and the sheath there is a gap, which reduces the rigidity of the support of the sheathing and, consequently, the mechanical impedance of the structure.

The impedance-acoustic method of non-destructive control is based on the change in the frequency of forced oscillations of the adhesive compound in the presence of non-adhesives therein. This method can be used in cases where the elastic modulus of the material (metals, fiberglass) of the lining of the glued product is quite large. Control of the surface of soft materials (rubber, foam) with this method is impossible. Impedance method is used for control of glued constructions with non-metallic lining, including honeycomb ones.

At the aviation enterprises, IAD-3 impedance-acoustic defectoscope [11] is used to control the non-gluing of metal-honeycomb constructions. Control can be carried out with one-way access to the surface. Due to the point contact of the sensor with the sheath, it is possible to control products with a small radius of curvature.

After checking the quality of the gluing, seal the inner cavity of the compartment with the honeycomb filler. Sealing composition of epoxy resin or elastomeric sealant is manually applied with the spatula. The same sealant is used to strengthen the honeycomb in places where fixing parts are installed.

Finished tail compartments of a blade for protection against pollution are mechanized in a polyethylene film at the unit SU-I (Figure 1.20) and transferred to the stamp for final assembly of the blade.

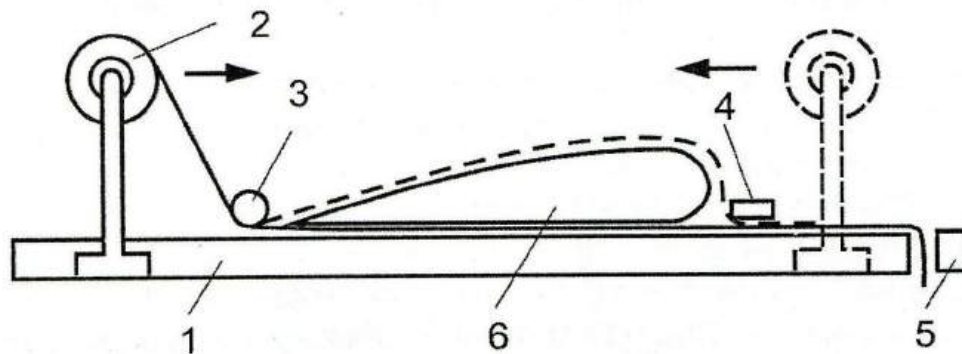


Figure 1.20 – Package layout of nodes of glued construction:

- 1 – table; 2 – roll of polyethylene film; 3 – roller electrode;
- 4 – electrode; 5 – clamping strap; 6 – packed node

Unit SU-1 allows us to pack glued structures of up to 7200x2500 mm and productivity up to 60 m² per hour.

2 TECHNOLOGY OF MANUFACTURING NONMETALLIC HONEYCOMB CONSTRUCTIONS

2.1 Structural and technological features of non-metal honeycomb structures

Global and domestic aircraft construction enterprises, like the State Enterprise "Antonov" widely use such constructive and technological solutions that belong to the class of integral structures of polymer composite materials (PCM) [10, 14], namely:

- frame structures (monolithic sheathing, supported by elements of the framework in the form of ribs, rifts, filled with foam);
- three-layer constructions with honeycomb filler of aluminum foil, polymer paper or fiberglass.

Aluminum foil hinges, which have high mechanical characteristics, have been used for many decades, including at the initial stage of constructing structures with polymer composites. The complexity of meeting a complex of technological requirements in the manufacture and sealing of metal honeycomb structures leads to the accumulation of moisture and the formation of corrosion in metal cells. Such a defect appears on planes during operation and reduces the reliability of these structures. In a honeycomb aggregate based on polymer sandwich brand PSP-1, which is used in the operation of aircraft, gradually replace the metal cells from aluminum foil. Scope of the use of polymer composites in the design of a modern aircraft is shown in Figure 2.1.

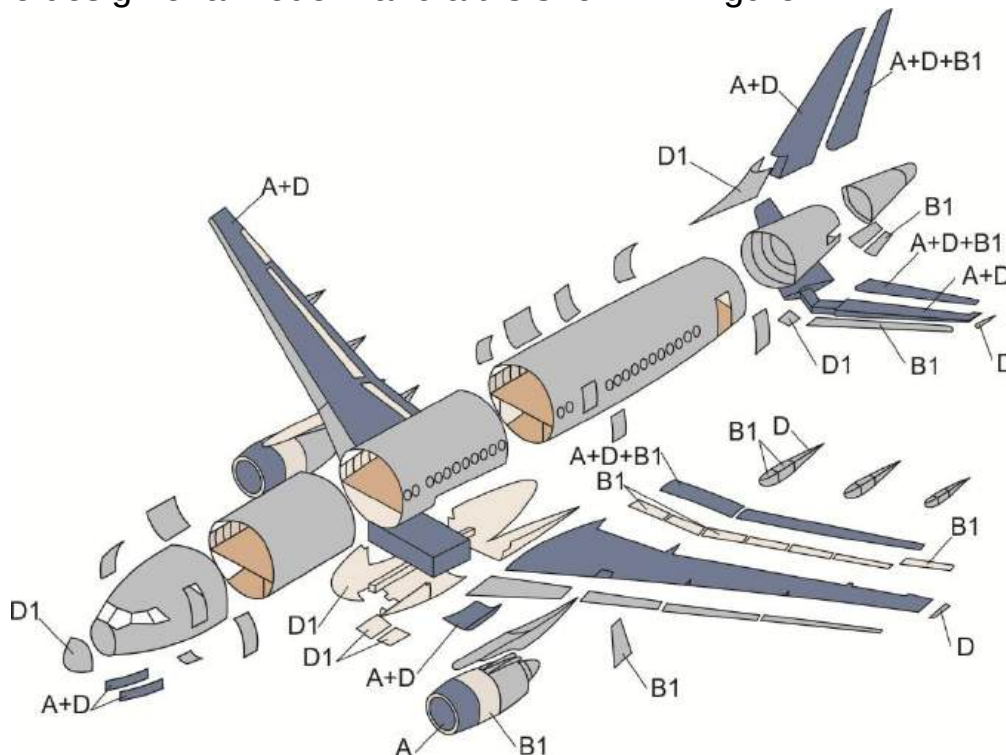


Figure 2.1 – Scope of application of polymer composites in aircraft design: A – carbon tape; D – glass fiber; B1 – carbon fabric for honeycomb constructions; D1 – glass fiber for honeycomb constructions

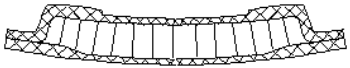
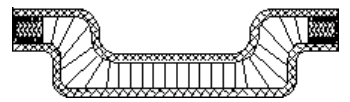
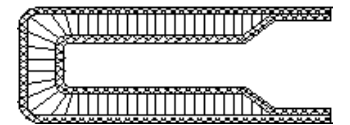
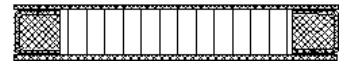
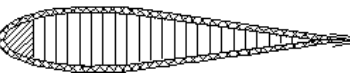
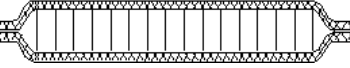
The use of polymer composites requires the creation of new computer methods for designing and developing technological processes and equipment. It should ensure their continuity in experimental and batch production. This is due to the fact that units with polymer composites technology are largely determined by the composition of technological equipment for their manufacture.

In the production of polymer composites honeycomb constructions for a modern aircraft, it is possible to implement two options:

- three-layer construction with carbon fiber plating and aluminum honeycomb filler or filler on the basis of the polypropylene layer PSP-1;
- an integral design of the type of sheathing with an auxiliary longitudinal or transverse longitudinal force set, formed simultaneously with the sheathing, forming one unit.

Panels and flaps of the outer contour of the fuselage, the nose and the panel of wing, the units of the wing mechanization, the steering wheel, the brake shields can be made in the form of a three-layer honeycomb structure with lining of organoplastic or carbon fiber (Table 2.1).

Table 2.1 – Typical variants of honeycomb structures with polymer composites

Typical variants of honeycomb structures made of polymeric materials		
Surface shape	Types of typical cross-sections	Installation area
Flat, double or single curvature		The panels of the wings and the fins, hatch covers, doors, doors for landing gear
Plane with linear bends		Boxes for protection of assemblies and communications
Single curvature with linear bends		Fairings of monorail mechanization of the wing
Flat, single curvature		Panels of the floor, hatch covers
Linear		Ailerons and flaps
Flat or single curvature		Hermetic shields, doors for landing gear

In the design of the tail compartments of blades with polymer composites modern helicopters include lining and ribs from organit 7T, honeycomb filler of polymer sandwich brand PSP-1 (Figure 2.2) [9].

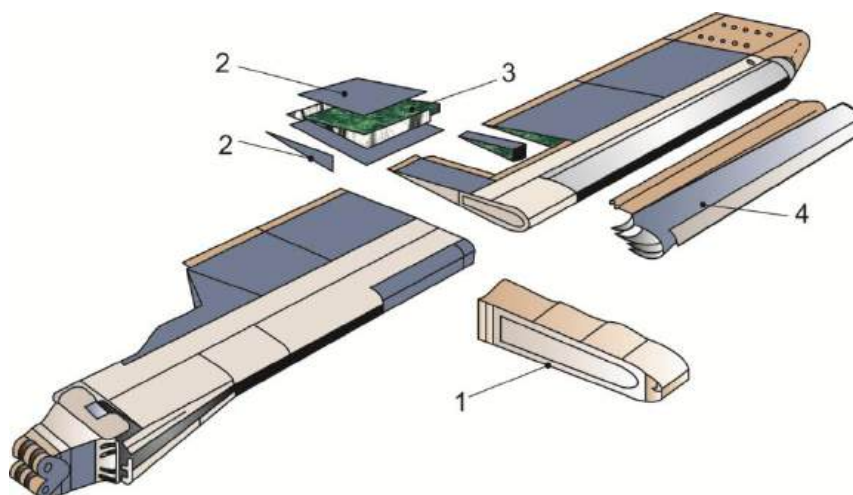


Figure 2.2 – The layout of the polymer composites in the helicopter blade:
 1 – glass fiber AK-9; 2 – organit; 3 – honeycomb filler from polymer cell layer PSP-1; 4 – glass fabric 33-100-70

In aircraft of the State Enterprise "Antonov" the replacement of metal cells to a polymer honeycomb filler PSP-1 is planned for the following structural hulls [10]:

- panels of the tail section of the wing of AN-148 and AN-70;
- the panels of the tail parts of fin and stabilizer of An-70;
- floor panels of the passenger cabin of AN-140 and AN-148;
- doors of cargo hatch for An-124 aircraft;
- hatch of nose cowl of An-124 aircraft;
- AN-148 auxiliary propulsion unit.

2.2 Technology of manufacturing of honeycomb constructions with polymer composites

The technology of manufacturing non-metallic three-layer panels with honeycomb filler of polymer sheet provides the following typical sequence:

- manufacture of polymer honeycomb filler;
- making layers of the outer and inner sheaths of carbon fiber or fiber-glass on the technological equipment;
- hardening on the molding equipment in the autoclave of the inner and outer sheaths;
- processing of a polymer honeycomb filler on a milling machine with CNC special fungal mills;
- gluing in an autoclave of an inner sheath and a cell filler;
- assembly of the inner sheath with a honeycomb filler and an outer sheath on a negative mould (outer sheathing from below);
- gluing in an autoclave of a three-layer panel;
- gluing quality control and geometric parameters of the nonmetal honeycomb panel with polymer composites.

2.2.1 Manufacturing of polymer honeycomb filler

The technology of manufacturing polymeric honeycomb filler PSP-1 was created in Research Institute of Mechanical Engineering NDITM (Dnipro) in 2001 on the basis of research by V.I. Slyvynskiy [8].

Polymer honeycomb filler is manufactured in the following technological sequence:

- application of glue strips of liquid glue VK-25 on roll polymer paper PSP-1 and assembly of the package (a device for applying glue strips of the model UNKP-1, automatic assembly of the package of model ASP-1);
- gluing of the cell package (hydraulically pressed with electric heating package of the model D-2938);
- cropping of the package (BR-125K model paper cutting machine);
- decomposition of the package on the workpieces (automated installation with CNC);
- cutting and milling of dies of a package (hydraulic press DB-2430, milling machine with CNC-FP-7M);
- stretching cell package (specialized installation URBP-1);
- thermal fixing of the stretched cell package (induction heating furnace).

The technological line for the production of polymer cell packages includes a unit for applying UNCP-1 adhesive strips, a hydraulic press with electric heating of the DB-2430 model for grouping of packages of 300-500 sheets of paper and the BR-125K paper cutting machine for cutting the cell package (Figure 2.3).

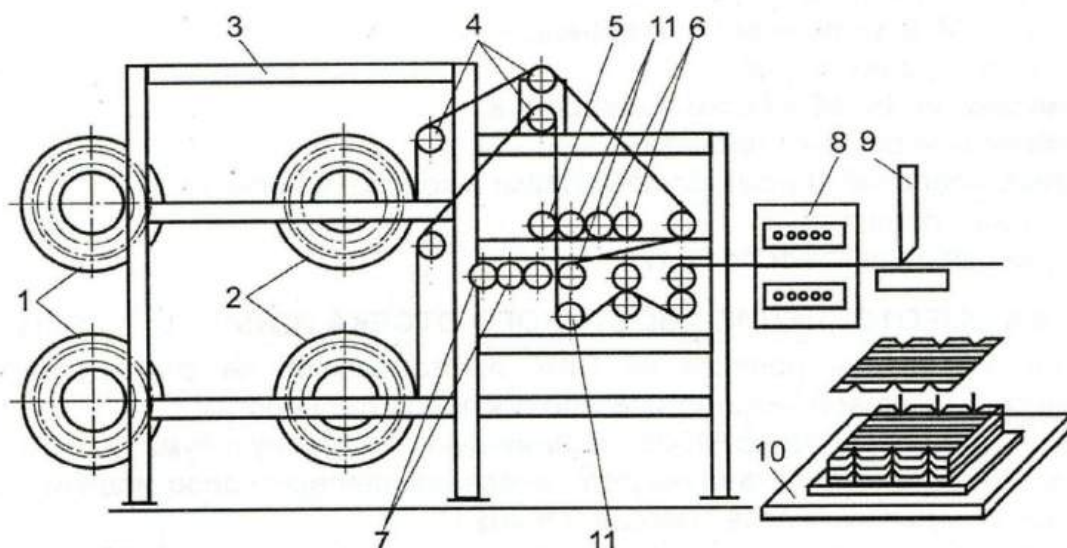


Figure 2.3 – The scheme of the technological line: 1 – rolls of paper; 2 – heater; 3 – bed; 4, 11 – guide rollers; 5 – clamping rollers; 6 – adhesive rollers; 7 – adhesive rollers; 8 – drying chamber; 9 – cutting device; 10 – package assembly device

Due to the fact that the thermal conductivity of the polymer paper is small, the package is warmed up by the microwave current, while the high strength of the filler is achieved, and the heating cycle of the package of 500 sheets does not exceed 20 minutes.

In the general process of obtaining a polymer cell filler, the technology of stretching glued packages into blocks and then fixing them before they become impregnated is of great importance. A distinctive feature of the technological process of stretching honeycomb filler from polymer paper is the need to fix the shape of a stretched cell block in the tool, because the polymer paper has a high elasticity and the free package after stretching changes form.

The URBP-1 unit for stretching a polymer honeycomb filler is a fixing unit for a stretched block (Figure 2.4).

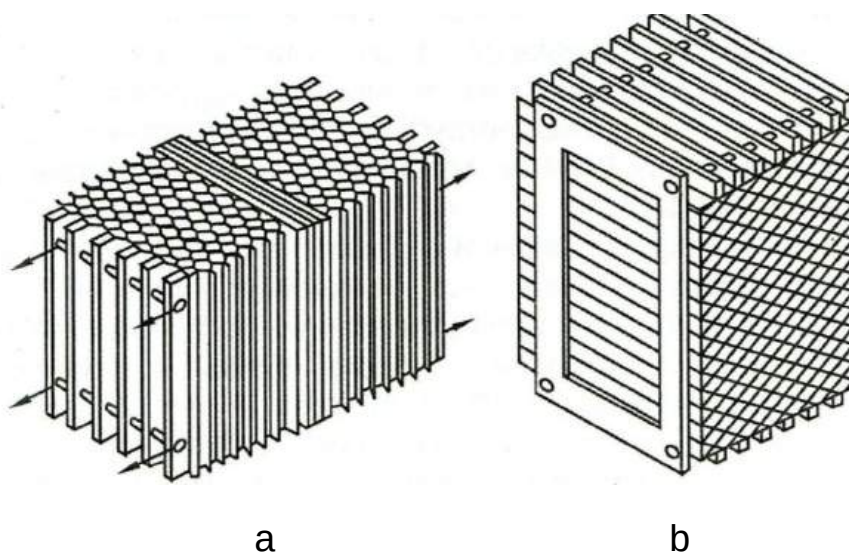


Figure 2.4 – Stretching scheme of the glued package (a) and fixing the block cell of polymeric paper (b)

Leakage of a glue substance of a fixed polymeric cell block of the size up to 600x750x2500 mm occurs at the installation of UPSS-1.

The installation of UNK-1P for application of a liquid adhesive composition on the edge of honeycomb fillers made of polymeric paper allows processing aggregate blocks in the size up to 4000x1600x200 mm at a speed of movement of blocks up to 6 m/min and a drying temperature up to 100°C.

The sheets of PPP-1 polymer paper are cut with fine saw (the tooth stroke is up to 5 mm) at a speed of 1000 to 1500 m/min and feed not exceeding 1 m/min.

Cell bags of polymer paper are cut on a horizontal band saw with a fine-grained dust from the working area in protective glasses and a respirator (Figure 2.5).

The stage of roughing the fungal cutter of the ends of the polymeric honeycomb aggregate on a special milling machine with CNC RFP-6 is shown in Figure 2.6.



Figure 2.5 – Cutting of honeycomb packages from polymer paper

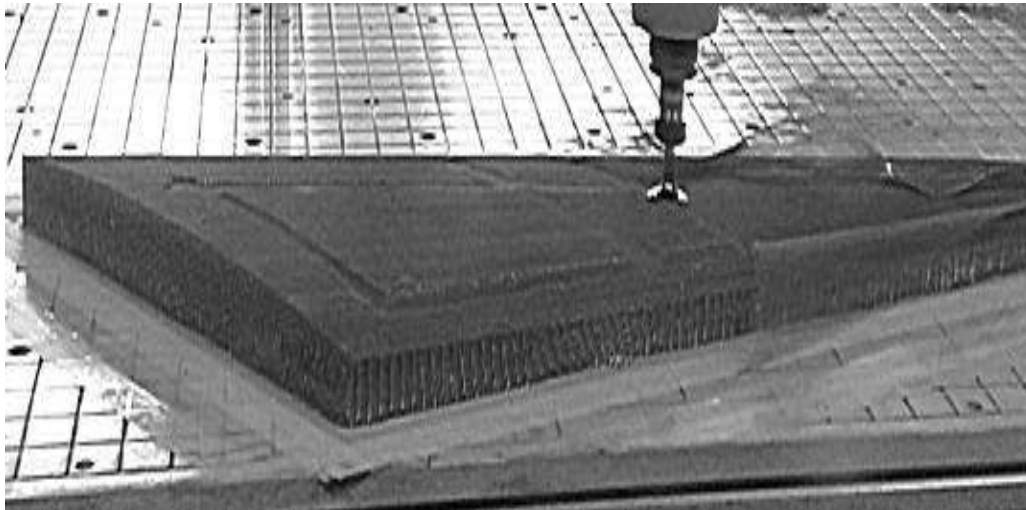


Figure 2.6 – The rough milling of the ends of the cell block

It is recommended the following mode of milling the ends of the cell unit: the milling speed of 18000 min⁻¹, minute feed – up to 3500 mm/min.

2.2.2 Autoclave molding of polymer composites sheathing

Formation is the technological process in which the material is solidified (polymerization of the connecting polymer composites), its final structure is created, the properties of the composite get maximum values, the shape of the product is fixed. During the formation of a special tool for sticking polymer composites exposed to the simultaneous influence of pressure and temperature in the autoclave. Manual process is the easiest way to prepare for the formation of low-load honeycomb structures with polymer composites of various dimensions and configurations.

The fabric is cut on a table with manual mechanized scissors on contour lines using a laser projector (Figure 2.7).



Figure 2.7 – Cutting the fabric using a laser projector

In order to improve the quality of the subsequent formation of products with polymer composites the layers of prepreg from the carbon tape for sheathing are laid out on special machines with CNC (Figure 2.8).

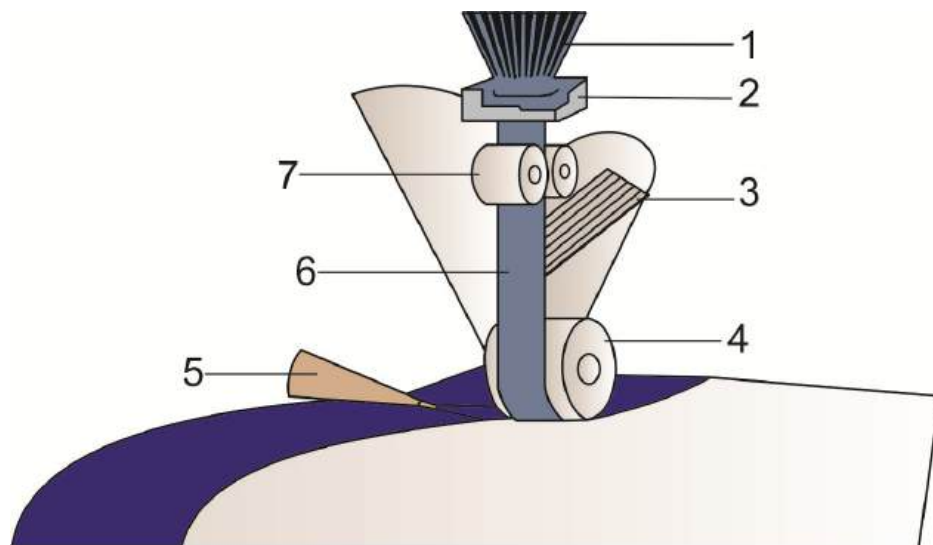


Figure 2.8 – Scheme of automatic prepreg tape layout: 1 – polymer composite fibers; 2 – tape shaper; 3 – knife; 4 – clamping roller; 5 – heating head; 6 – prepreg tape; 7 – rollers of tape feed

The required number of layers and corners of the layout is provided by the headform automatically under the control program. Built-in pressure and temperature control of the clamping roller determines the stability of the technological process and the high quality of the properties of molded products.

Diagram of preparation of the adhesive form for the autoclave formation of the sheathing from the layers of carbon or fiberglass is shown in Figure 2.9.

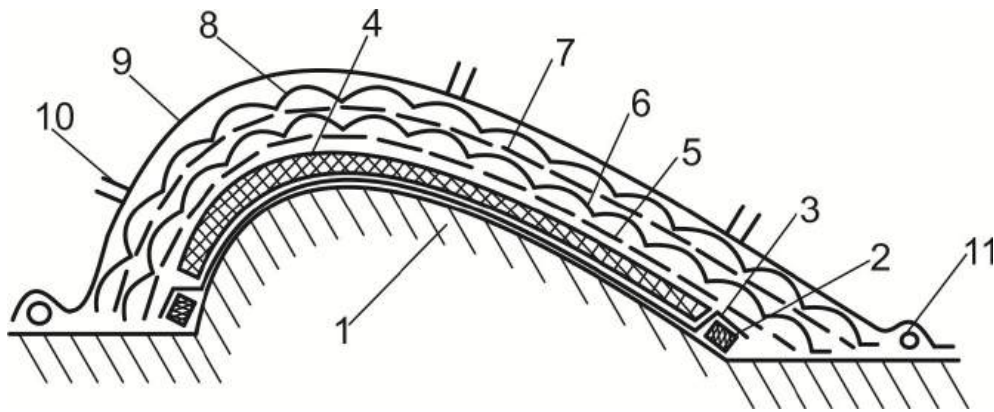


Figure 2.9 – Scheme of preparation of the sticker form

The layout of the layers on the technological equipment for auto-key forming is performed in the following sequence [8]:

1. De-oiling of the working surface of the adhesive form 1.
2. Installation of limiters 2 and application of antiadhesive layer 3.
3. Laying the required number of layers of pre-cut dies from carbon or glass fabrics in the form of prepreg 4.
4. Brushing of the pre-loaded sheets of pre-heated non-rigid roller to seal the package and remove the air bubbles.
5. Mounting in the zone of technological acceptance of the thermocouple, providing the automatic temperature mode of solidification in an autoclave.
6. Installing on the outer layer of a package of perforated split film 5 and a suction layer from a fabric of bulk weaving 6.
7. Establishing the core 7, which is a rigid shell of tone-colored metal, which is an equidistant stacking surface.
8. Mounting of drainage layer 8 to ensure uniform dispersion of the vacuum under a vacuum bag.
9. Adjustment for the size of the sticker form of the vacuum bag 9 from the gas-tight film with the fittings 10 for connecting the vacuum system.
10. Sealing of the created vacuum bag with an elastic bundle 11.

Figure 2.10 shows the packaging of the stick-shaped form in a vacuum bag. This operation requires compliance with special requirements regarding the purity of industrial premises and clothing.

Autoclave is a sealed, heat-insulated container with a solid metal body of a cylindrical shape, mounted on a base. The enclosure is closed by a hermetic lid of a spherical shape. The working chamber of the autoclave includes mounted rail path for moving a cart with a plaster shape in a vacuum bag. An integral part of the autoclave equipment is a vacuum system to create excess pressure.

The pressure in the autoclave is created by means of a compressor or by evaporation of liquid nitrogen, the temperature is created by built-in heating elements or aerodynamic blowing.



Figure 2.10 – Packing the sticker into a vacuum bag

Figure 2.11 shows the loading of the sticker forms into vacuum autoclave with vacuum bags for the formation of the AN-148 airplane plates.



Figure 2.11 – Load into the autoclave of the sticker forms

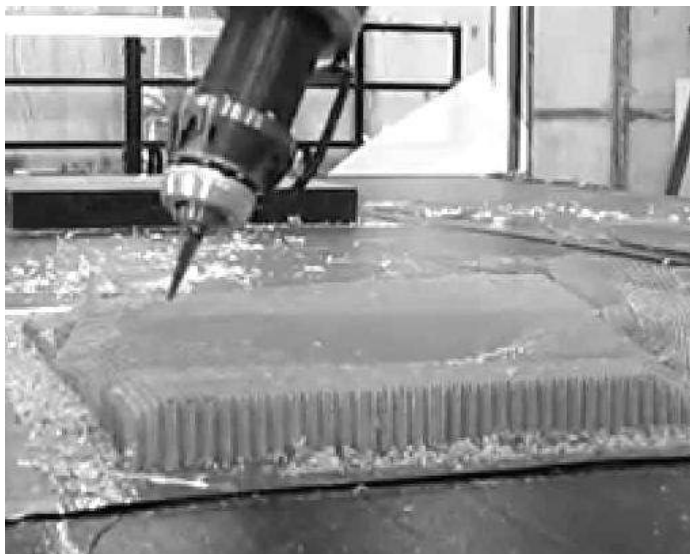
Autoclaves provide heating of glued composite units and aggregates to a temperature of 350°C at a pressure up to 3 MPa.

2.3 Manufacturing of the tail unit of the blade with polymer composites

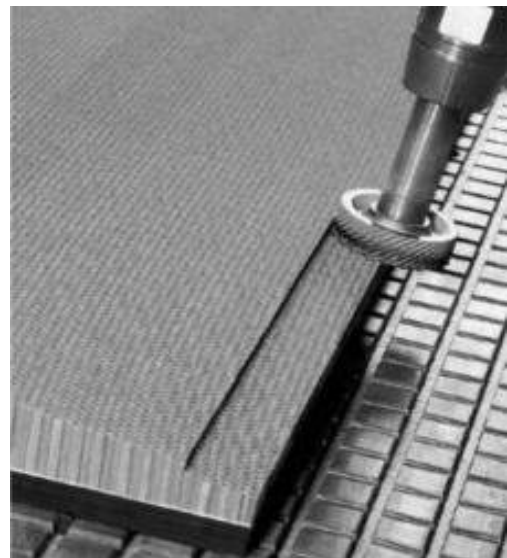
Polymer honeycomb filler of the tail unit of the helicopter blade is made according to the route technology (see v. 2.2.1).

Further work on the production of the tail unit of the blade with polymer composites is carried out in the following technological sequence [9]:

- making of sheets from the organit brand 7T (unit for the formation of sheathing);
- Manufacturing of ribs from organit brand 7T (unit for the formation of ribs);
- creating a roughness of lining and ribs to reduce the smoothness of the surface (unit to provide surface roughness);
- application of liquid glue VK-9 on the end of polymeric honeycomb aggregate (UNK-1P unit for glue application);
- bending of the film glue VK-3 to the sheathing and ribs (rolling unit SPK-1);
- bonding of the honeycomb filler with the bottom sheathing and ribs (specialized unit with CNC for gluing of tail compartments);
- processing of the top surface of the honeycomb aggregate (a special machine with CNC RFP-6) (Figure 2.12);
- folding-gluing of the tail section (specialized unit UCX-2 for gluing tail compartments).



a



b

Figure 2.12 – Milling of the top surface of the honeycomb filler of the tail section: a – rough on the fin; b – clean

The honeycomb filler on the ends is milled with special fungal cutters from high-speed steel with diameters from 12 to 70 mm.

2.3.1 Formation of the tail unit of the blade

Coverings of the tail unit of the blade are made by "dry" method. The scheme of laying the tail section of the tail unit using a vacuum bag is shown in Figure 2.13.

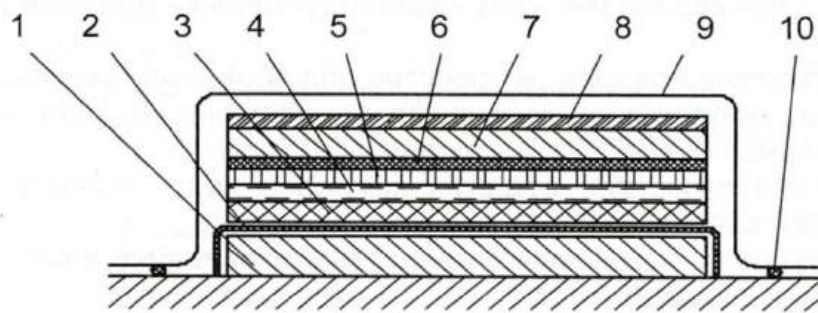


Figure 2.13 – Scheme of sheathing of the tail unit of the blade

On a plaster surface of form 1, a separate layer 2 is applied to prevent adhesion between the connector on the fabric of the prepreg 3 with the base. A separate layer is laid with a pack of prepreg and a porous film 4. An excessive connector in the package, flowing through the porous film, is absorbed by the adsorption material 5. On the upper separating layer 6, a metal core 7 is applied to uniformly transfer the formation pressure to the package and provide the required quality of the surface of the sheathing. The drainage layers 5 and 8 divert the evaporating connector components out of the vacuum bag 9 that are sealed with the tow 10.

Figure 2.14 shows a vacuum bag with a nozzle for autoclave molding of the tail section.



Figure 2.14 – Vacuum bag for forming the shell of the compartment

Ribs of the tail section are made with the use of special adhesive forms. After assembly, the product is formed in a vacuum bag placed in an autoclave or a press chamber (Figure 2.15). On form 1, after pre-adhesive preparation, is laid out with a pre-cut out prepreg 2 package, after which a rubber bag is placed after a separate anti-adhesive film 3.

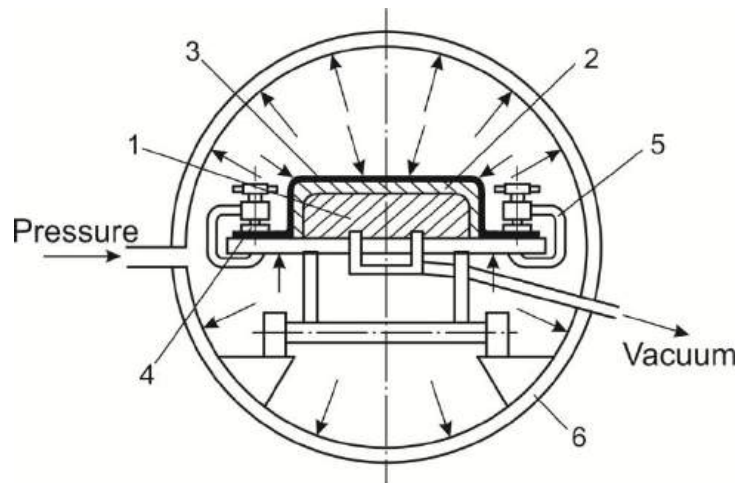


Figure 2.15 – Scheme of the formation of the ribs of the tail section

Then the form is sealed with clamping rings 4 and clamps 5. The form is placed in the autoclave 6. Before assembly of the tail unit of the blade, the working surface of the assembly device of the frame structure is covered with separating material.

The parts of the sheathing on the assembly device are fixed with fixing elements - pins and a sticky tape, while composing a separate film is removed from glue film. To seal the vacuum bag using an elastic harness is used. After pumping air from the bag, assembly with the tail unit of the honeycomb structure is placed in the autoclave (Figure 2.16).

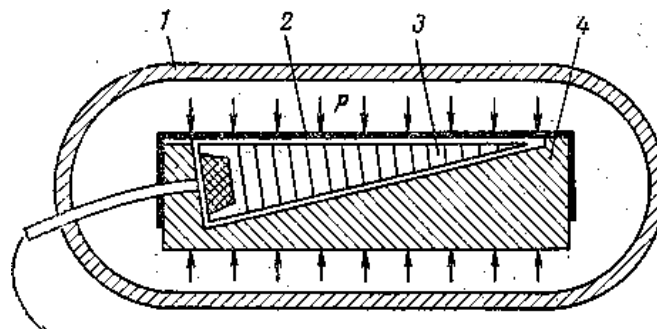


Figure 2.16 – Scheme of gluing tail unit: 1 – autoclave; 2 – vacuum bag; 3 – tail unit; 4 – assembly device

The drainage channel through the fitting is connected to the autonomous vacuum autoclave system. The connector hardens for a given thermal mode and an excessive pressure of 0.8 ... 3.0 MPa.

2.4 Features of the processing by cutting polymer composites

The characteristic features of cutting by polymer composites are as follows:

- the heterogeneity of the structure of the material and the different hardness of its constituent parts, making it difficult to obtain a low surface roughness. As a result, the permitted operation of tool is deter-

mined by the technological criteria of blunting, primarily by increasing the roughness of the surface;

- unsatisfactory heat removal from the cutting zone due to the reduced thermal conductivity of the polymer composites and, consequently, overheating of the cutting edges of the tool. For this reason, the criterion for the maximum permissible speed of cutting is often the appearance of traces of coal on the surface of the layer of the treated surface;
- intense dust formation, which leads to removal of dust and chips from the cutting area with the help of special devices.

The listed peculiarities of cutting by polymer composites suggest that simple transfer of the laws of the process of cutting metals on these materials is unacceptable [12].

Drill bits with polymer composites are one of the most common types of processing. Figure 2.17 shows the recommended forms for sharpening the cutting part of the drills from high-speed steels for polymer composites processing.

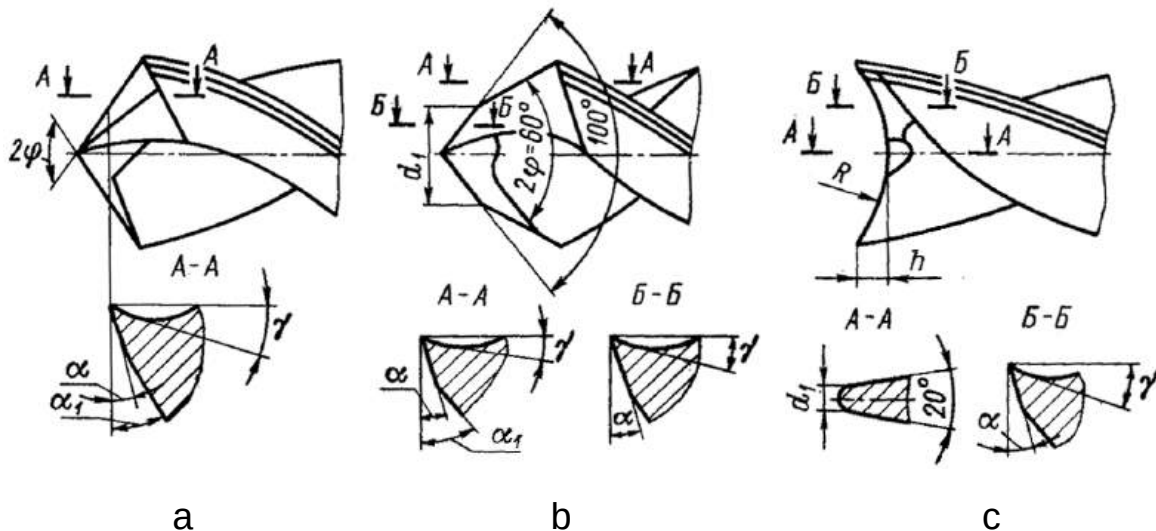


Figure 2.17 – Forms of sharpening of the cutting part of the drills from high-speed steels: a – NPL; b – DPL; c – PRK

Drills of high-speed steels with sharpening forms of the cutting part of the NPL (normal), DPL (double) and PRK (with trimmed cutting edges) types are used for drilling holes in glass and carbon plastics, drill bits of hard alloys with the same forms of sharpening in glass, carbon and boroplastic dies.

The greatest impact on the quality of the hole processing is the angle $2\varphi < 110^\circ$ with the drill bit. Accepting the angle of $2\varphi < 110^\circ$ during the drilling of thin packets is not feasible due to the danger of creating a "plugged" hole.

With the increase of the anterior angle, the roughness of the surface of the hole increases, there is a "loosening" of the edges of the openings, especially when the corners of the drill holes exit. In order to prevent sticking of chips to the tool during drilling, it is recommended to apply molybdenum disul-

fide to the surface of the grooves of the drill. During the polymer composites drilling, it is not necessary to apply cooling liquids, as they are mixed with dust and form a paste that complicates drilling. The cutting mode during drilling polymer composites is chosen based on providing the required surface roughness parameters and knowing the period of tool stability. Excessively intensive treatment prevents the removal of saw blade chips, promotes the heating of the tool and further fastening of chips to the surface of the grooves of the drill.

Glass and carbon plastics are milled with hard-alloy mills. The most appropriate tool is tungsten cobalt hard alloys. The geometrical parameters of the cutting part have a great influence on the stability of the tool, so they must be selected correctly (Figure 2.18).

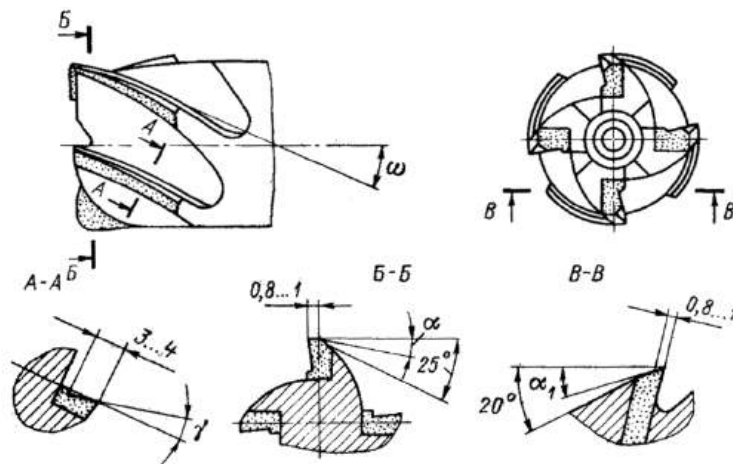


Figure 2.18 – Typical construction of a carbide end cutter

In order to avoid stratification, polymer composites shall be processed according to the associated milling scheme, since the rotation of the cutter must coincide with the direction of movement of the presentation of the work-piece.

When cutting the products with polymer composites, toxic dust and fine chips are formed. Exhaust ventilation is designed to remove chips and dust from the cutting zone (Figure 2.19).

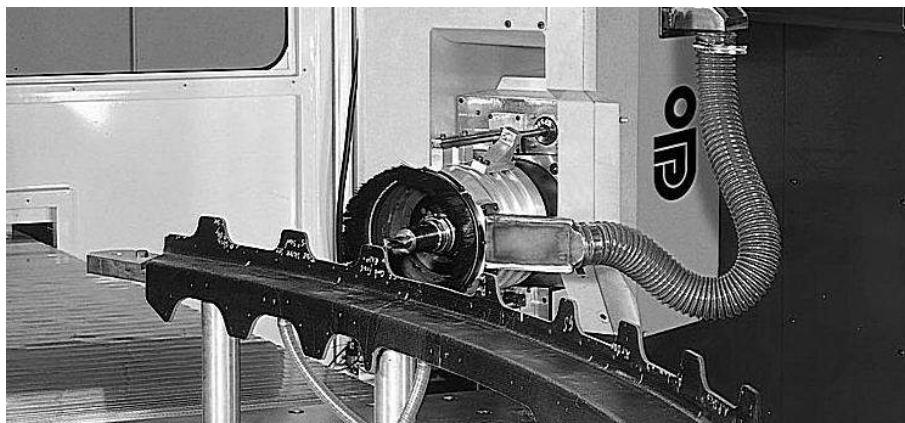


Figure 2.19 – The collector on the spindle of the milling machine

For exhaust ventilation to work efficiently, it is necessary to have an appropriate system of pipelines and special receiving dust collectors in the working area of the machine tool.

2.5 Quality control of manufacturing of products with polymer composites

The main types of defects in products with polymer composites with honeycomb filler are strapping in the sheathing (Figure 2.20, a) and non-adhesive coatings to the filler (Figure 2.20, b).

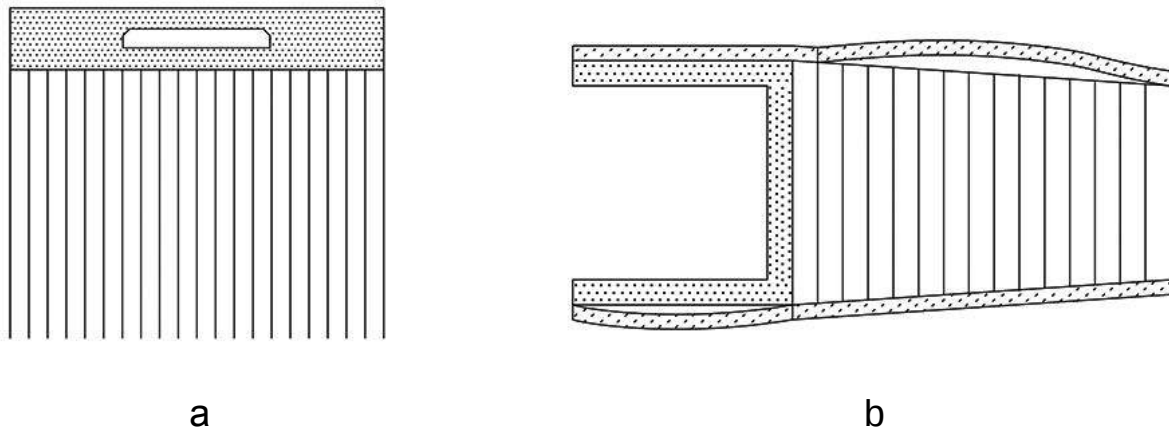


Figure 2.20 – The main types of defects in products with polymer composites with honeycomb filler

Quality control of products with polymer composites significantly differs from the control of metal parts. polymer composites are non-conducting materials, therefore, they significantly dampen the vibrations and are formed in the process of manufacturing the structure. This does not allow us to standardize the requirements for the supplied material, and makes it necessary to carry out general or selective control of the material already in the finished structures. In addition, due to the specific properties of polymer composites, it is not possible to fully use flaw detectors used to control metals [11]. This contributed to the development and implementation of new instruments based on acoustic, X-ray and optical methods of control. Acoustic methods due to their mobility make up more than 60% relative to other methods of non-destructive testing. For example, non-destructive quality control of products from polymer composites bonding for many years applied acoustic defectoscopes AD-40I, AD-50U, optic-fiber endoscope of the model RVP-456, and automated control of the non-nucleus control UCN-4P.

The modern acoustic defectoscope AD-60K is intended for non-destructive control of products with polymer composites using a combination of methods of impedance and free oscillations. Defectoscop allows us to connect any type of impedance (combined, separate-combined) and percussion (with piezo elements or microphone) converters.

Figure 2.21 shows the control phase separation in the lab specimens multilayer panels polymer composites.

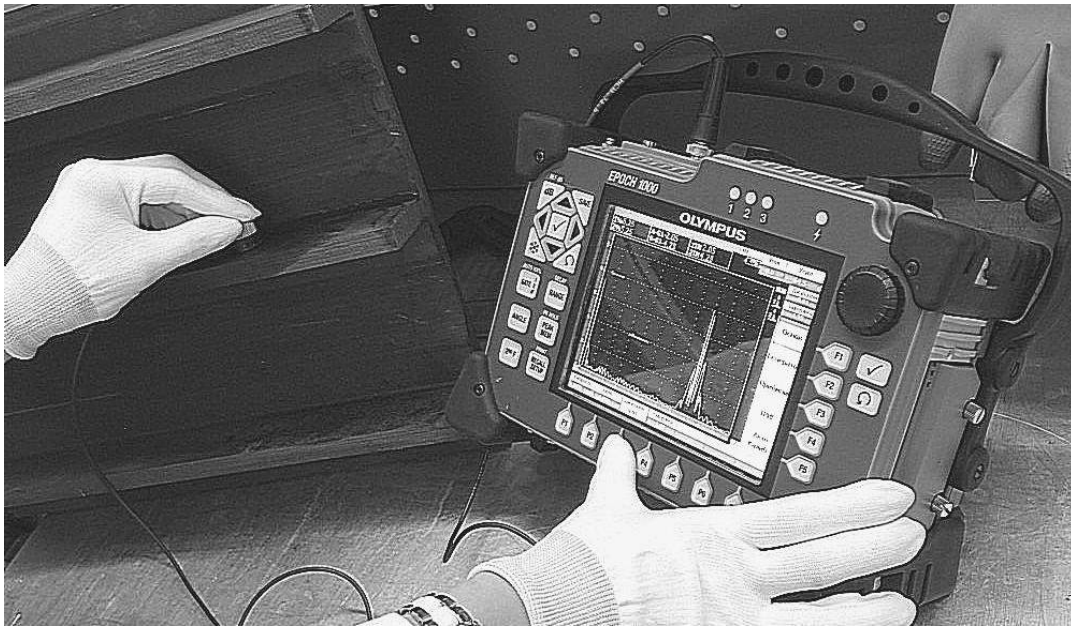


Figure 2.21 – Bundle control in multi-layer polymer composites

The modern impedance defectoscope ID-91m is designed to detect local bundles and integrity defects in multi-layer adhesive structures with polymer composites. The signal level displayed on the defectoscope indicator is proportional to the mechanical impedance of the control object at the point where the converter is installed.

Figure 2.22 shows the control stage in laboratory conditions for non-sticking of the sheathing to the cell-filler with polymer composites of the sample.

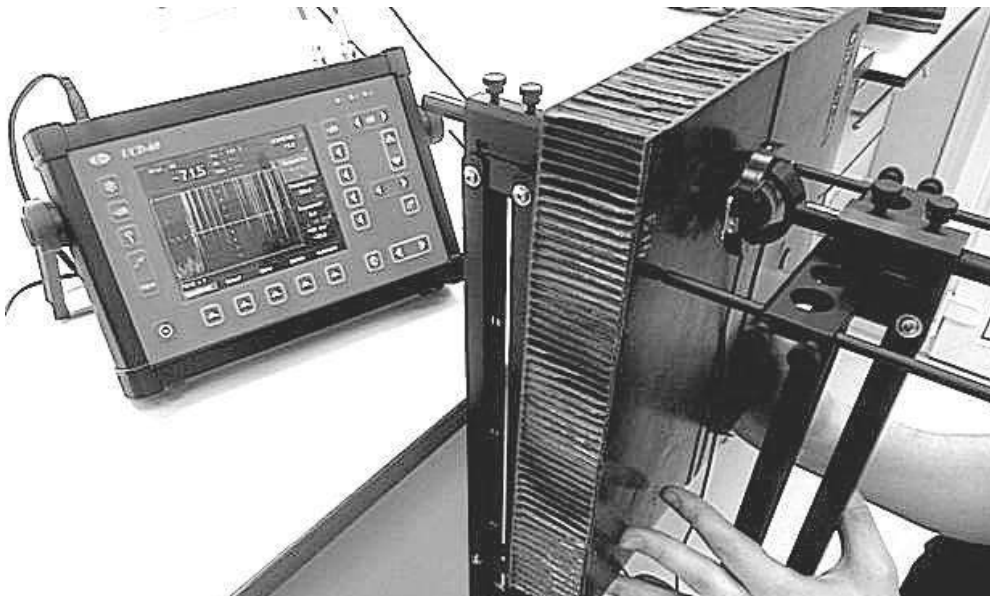


Figure 2.22 – Control of non-sticking of the sheath to the honeycomb filler

Modern automated non-stick control systems for polymer composites products have a working area up to 30 meters in length (Figure 2.23).



Figure 2.23 – Automated non-stick control unit

The quality control of products with polymer composites is used at all stages of composite structures creation: the development of the technological process; production certification; detection of changes in the internal structure of products during tests and in the period of operation; study of new design and technological solutions.

The introduction of manufacturing processes for polymer composites products requires the fundamental technical re-equipment of enterprises, the development of specific processes for the processing of polymer composites, the implementation of numerous design and research related to the development of new equipment, facilities and specialized computer software.

In the aviation industry of Ukraine, processes of manual and partially mechanized calculation of large-sized structures, automated winding, autoclave and thermocompressor formation were mastered; manufacturing of three-layer honeycomb panels and monolithic integral structures, riveted and bolted connections of knots and aggregates with polymer composites, non-destructive testing was introduced.

It should be noted that in recent years, in connection with the trend of unification of standards for the production and testing of aviation applications of polymer composites, the standards of production and certification to the process of updating and creating new international standards involved the largest manufacturers of aircraft technology [14]. The development of supply of domestic aviation equipment abroad has led to the need to improve domestic industry standards to the international level.

3 FEATURES OF SHEET STAMPING OF HARD-TO-FORM MATERIALS

3.1 The main characteristics of high-strength stainless steels and titanium alloys

Steel **BHC-2** (08X15N5D2T) is chromium-nickel stainless steel of martensite class, age-hardened. It is used to make lining and parts of the internal set of the airplane operating in different atmospheric conditions and in contact with fuel at temperatures up to 400°C. Sheets of steel BHC-2 in the normalized (tempered) state have a satisfactory plasticity, they can be used for stamping parts of medium complexity. This steel is most plastic after annealing at a temperature of 640°C.

Strengthening of steel is carried out by thermal treatment, which consists of hardening at a temperature of 950°C and aging at a temperature of 450°C.

The strength level is $\sigma_B = 1250$ MPa.

Steel **CH-3** (08X17N5M3) is stainless chromium-nickel-molybdenum steel of transitional (austenitic-martensitic) class. It is used for the production of panels and internal components, as well as welded units of products operating in atmospheric conditions at a temperature of up to 500°C. Sheets of steel CH-3 after high temperature tempering (from 1050°C) have high ductility and can be subjected to a deep extract, bending with small radii of rounding and other technological operations, which require a high degree of deformation. Steel can undergo deformation strengthening rolling obtaining semi-hot and tempered states. Strengthening of steel CH-3 is achieved by quenching, starting from 910°C, by cold treatment at -70°C and subsequent aging at 450°C. Strengthening semi-hardened and tempered steel CH-3 is carried out by aging at 450°C.

The strength level is $\sigma_B = 1250$ MPa.

Steels **EI878** (12X17G9AN4) and **EI654** (15X18M12C) are welded stainless steels of austenitic class which have high corrosion resistance in air in humid environment. Steels EI878 and EI654 can also be used in aggressive environments and in contact with fuel. The steels have high ductility, are well stamped, welded, not strengthened by thermal treatment. High-temperature one-time quenching provides high corrosion resistance as a result of the formation of a single-phase austenitic structure. The hardness of the steel is high (25 ... 40 %).

Alloy **OT4-1** is a low-titanium alloy of the Ti-Al-Mn system, which has high plasticity and low strength (700 MPa). The special liveliness of the alloy is its high technological ductility. The alloy is well deformed in hot and cold conditions. Sheet punching of parts, as a rule, is carried out in a cold state. When stamping complex parts intermediate annealing is used. OT4-1 alloy has a high thermal stability and does not get crumbly at temperatures up to 300°C. It is used in annealed state for the manufacture of parts of a wide range of internal set of airplanes.

The **OT4** alloy Ti-Al-Mn contains a slightly larger amount of aluminum (3.5–5 %) than the OT4-1 alloy, and is characterized by higher strength and heat resistance. It is used for the manufacture of parts of the internal set and welded units of the aircraft, working for a long time at temperatures up to 300°C. The alloy is well deformed in hot condition and limited in cold (only for the manufacture of parts of simple form). The temperature range of the deformation is 850 ... 1000°C. Cooling is carried out after stamping in the air. The burning of sheets for the removal of carcasses is carried out at a temperature of 680 ... 730°C. The alloy has a high thermal stability and does not get crumbly with prolonged work under voltage at a temperature of up to 400°C, well welded argon-arc and contact (point, roller, static) methods. The only type of thermal treatment of an alloy is annealing, which is used to remove internal stresses.

The alloy **VT20** is an alloy of the Ti-Al-V-Mo system used for the manufacture of sheet metal parts and weld units which for a long time can operate at 450°C (6000 hours) and 500°C (3000 hours), as well as short-term (up to 5 minutes) at temperatures up to 800°C. The alloy VT20 is well deformed in a hot condition and well welded in all the ways used for titanium alloys. The mechanical properties of the welded joints are not inferior to the properties of the base metal.

The increase in the plasticity of the welded joint occurs after annealing at a temperature of 700...800°C. Annealing is the only type of thermal treatment of the alloy. Annealing of sheets is carried out at a temperature of 700...800°C, followed by cooling in the air [4].

3.2 Sheet material cutting

Cutting works include all types of work related to the execution of separate operations, that is, the manufacture of flat parts and workpieces for spatial parts.

The efficiency of cutting sheet materials in the forging and stamping production is determined by a set of organizational and technical solutions, taking into account the economic feasibility of using one or another method of cutting. First of all, it should be noted that in order to increase the efficiency of cutting works at the plant, it is advisable to create a specialized cutting workshop based on cutting sections of pre-stamping workshops.

Nowadays the technology of sliding deformation has become the most widespread in the forging and stamping industry. This technology is realized using scissors of various designs (guillotine, roller, vibration, etc.) or stamps on mechanical presses. The equipment (scissors, press) available in the workshops is oriented mainly on the processing of aluminum alloys and other low-strength materials. An attempt to deploy on this equipment high-strength stainless steels and titanium alloys inevitably leads to a sharp decrease in the stability of the cutting tool, the quality of cutting and, eventually, to lowering econom-

ic performance. Maintaining the stability of the cutting tool and quality at an acceptable level is possible by increasing the rigidity of the equipment and making the cutting tool with better quality materials.

Existing two-disk scissors allow us to cut the material with a strength of 1350 MPa in thickness no more than 1.2 mm or a strength of 500 MPa in thickness up to 2.5 mm. In modern production, 40% of the parts subject to trimming have large thicknesses: up to 3 mm from steels and up to 5 mm from aluminum. The stability of the tool for cutting steels of maximum thickness does not exceed 20 minutes. Strengthened roller scissors (mod. K30.029) allow us to process material with a strength of 2000 MPa in thickness up to 3 mm. In this case, the quality of cutting increases and the stability of the tool increases in 4-5 times [1].

It is noteworthy to mention using simplified lamellar dies for cutting parts with overall dimensions up to 300x400 mm from high-strength stainless steels and titanium alloys up to 1.5 mm in thickness [4]. Figure 3.1 shows a typical package of lamellar cut-off die.

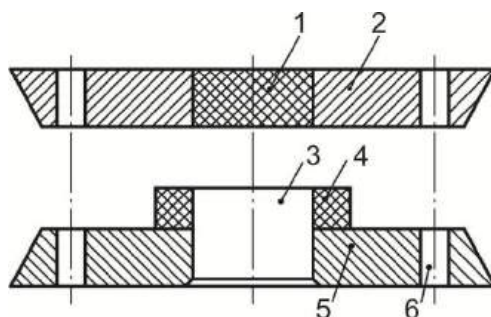


Figure 3.1 – Package of lamellar stamp: 1 – pusher; 2 – matrix; 3 – punch; 4 – stripper; 5 – punch holder; 6 – holes for fixing the package in a universal block

The working elements of the stamp are usually made of steel 20, cemented and tempered. The thickness of the plates of the matrix and punch holder is 8 ... 10 mm. Pusher 1 and stripper 4 are polyurethane. The matrix plates and the punch holder are installed in the universal block on the openings 6, processed in a special conductor, which is also used to handle the holes for fixing pins in the universal block. Recently, for mounting the package magnetic blocks are often used. In these blocks plates are mounted with electromagnets stamp by magnetic attraction. It was possible to significantly reduce the cost of using such stamps due to the use of cast matrices on a zinc-based foundry alloy (ECB), the chemical composition of which is given in Table 3.1. The strength of the alloy is 280 MPa.

Table 3.1 – Chemical composition of the ECB alloy

Content of components, %					
Al	Cu	Cr	Mg	Si	Zn
4.6...5.0	3.4...4.0	0.1...0.2	0.5...0.8	0.3...0.5	Rest

The main advantage of the stamps from the ECB alloy is that the manufacturing process eliminates the most costly fitting operation of the matrix of the punching because the matrix is cast through the punch. The alloy is reversible, which allows us to recast it repeatedly. In addition, it has a low melting point (380...400°C) and a satisfactory fluidity, which allows casting matrices of complex configuration. The casting of matrices is carried out in a furnace with rapid cooling in water from a temperature of 250...270°C to a room temperature, which increases the hardness and stability of the matrices.

For cutting down of small details, die-molds with casting operating parts (matrices, strippers, punch holders) from the alloy on the basis of copper (OC) are used. The matrix for precisely manufactured punch in this case is cast at a temperature of 1350°C. For the manufacture of dies with matrices of both zinc alloy and stamps with matrices from the alloy of the OC, punches from steels U8A, U9, X12M are used, heat-treated to HRC = 56...60.

The favorable combination of physical and mechanical properties of punches and matrices allows us to obtain parts made of non-ferrous alloys, stainless steels and titanium alloys up to 1.5 mm thick without burrs. The stability of the stamps at the same time is as follows: with matrices of zinc alloy – up to 1500 pcs., with matrices from the OC alloy - up to 10 thousand pcs. The use of stamps with cast matrices can reduce the cost of scarce tool materials; eliminate highly skilled work on matrix proofing and fitting; reduce the complexity of manufacturing of stamps in 3–5 times; reduce the cycle of manufacturing of stamps by 3 times.

Large-scale workpieces at the enterprises of the industry are curvilinearly cut on different milling machines. Implementation of cut-off milling portal CNC-machines RFP-1 and RFP-2 designed at Research Institute of Aviation Technology allow us to cut dies in the sizes of 11000x2000 mm and 6000x2000 mm, respectively, and made it possible to significantly increase the technical level of curvilinear cutting of sheets of aluminum alloys. The listed specialized cutting machines are single-speed, oriented to the processing modes characteristic of aluminum alloys. The custom speed of cutting in the processing of light alloys and high-strength titanium and steel varies. Therefore, it is not possible to use these machines to cut dies from stainless steels and titanium alloys.

At individual enterprises, large-sized dies from high-strength materials are cut on CNC machines FП-17, 6N13GN1, which can provide the necessary processing modes. In this case, taking into account the strength properties of the processed materials, end mills with a working part made of material VK-8 and 16...25 mm in diameter are used. A significant part of the expensive material of cutting sheets, goes for chips and the costs of cutting tools are large.

In this regard, there are doubts about the economic feasibility of milling for solving the problems of curvilinear decomposition of high-strength materials. Such a technology of decomposition is possible and should be used in the case

where the proportion of high-strength materials in the overall structure of the materials used is small. The growth in the use of high-strength steels, titanium alloys and other hard-to-process materials will require the re-equipment of production with new, up-to-date high-performance equipment using concentrated energy streams.

3.2.1 Laser cutting

Nowadays laser cutting is one of the most advanced technologies in the field of cutting sheet material, which opens unlimited possibilities for the manufacture of products of complex forms from various materials, including hard-to-deform materials.

The principle of gas-laser cutting of sheet materials is to blow the material in a molten state by simultaneously influencing the laser beam and auxiliary gas under pressure to create slits in the material (Figure 3.2). The effect of the laser beam leads the material to a melting point and above.

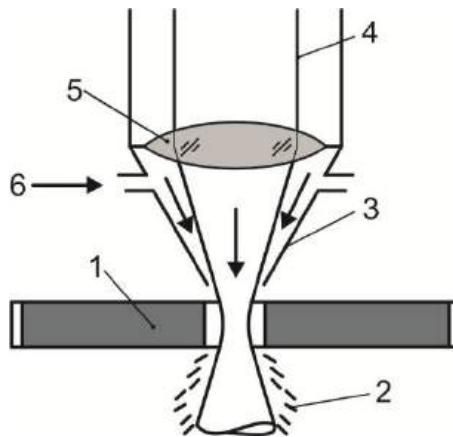


Figure 3.2 – The principle of gas-laser cutting of sheet materials:

- 1 – the material; 2 – slag; 3 v cutting nozzle; 4 – laser beam;
5 – focal lens; 6 – auxiliary gas

The laser radiation heats, melts and evaporates the material along the expected cut, and the flow of auxiliary gas removes the products of destruction. When using oxygen or air when cutting metals on the surface of the formation of oxide film, which increases the absorption capacity of the material, and as a result of the exothermic reaction is allocated a fairly large amount of heat.

The influence of the laser radiation flux on the metal during cutting can be characterized by the general provisions related to the absorption and reflection of laser radiation, the propagation of the absorbing energy by the volume of the cut material, taking into account the thermal conductivity, as well as on a number of specific features.

In the area of laser beam exposure, the metal is heated to the first temperature of fracture, i.e. melting. When further absorption of the radiation occurs melting of the metal and the phase melting point moves deep into the material. The energy effect of the laser beam leads to a further increase in

temperature, which reaches the second temperature of destruction – boiling, at which the metal begins to actively evaporate.

Consequently, two mechanisms of laser cutting are possible, melting and evaporation. However, the latter mechanism requires high energy costs, it can only be used for cutting rather thin sheet metal. Therefore, in practice, cutting is performed by melting. At the same time, in order to significantly reduce energy consumption, increase the thickness of the processed metal and cutting speed, an auxiliary gas injected into the cutting zone to remove the products of destruction of the metal is used. Typically, as auxiliary process gas, oxygen, inert gas, or nitrogen are used (Table 3.2).

Table 3.2 – Selection of auxiliary gas

Auxiliary gas	Cut material
Argon, helium	Titanium alloys
Nitrogen, helium	Stainless steel and structural steel
Oxygen	Low alloy steels and aluminum alloys

Laser cutting with neutral gas is usually used in cases where there is an undesirable oxidation of the metal edges, for example, when cutting stainless steel, titanium, etc. The efficiency of cutting in a neutral gas is lower than laser-oxygen cutting, where there are additional heating sources as a result of chemical oxidation reactions.

Laser cutting with oxygen is characterized by the fact that the interaction of oxygen with the heated metal occurs exothermic oxidation reaction.

Oxygen during gas-laser cutting performs a triple function:

- promotes preliminary oxidation of the metal and reduces its ability to reflect laser radiation;
- the metal ignites and burns in the stream of oxygen, resulting in extra heat, which increases the effect of laser radiation;
- the oxygen jet blows and takes away from the cutting area the molten metal and its products of combustion, providing a simultaneous flow of gas directly to the combustion front.

Depending on the properties of the cutting metal, two mechanisms of gas-laser cutting are used. At the first significant contribution to the overall heat balance is the warmth of the reaction of combustion of the metal. Such a mechanism is usually used for cutting materials that are prone to ignition and combustion below the melting point, and it forms liquid oxides. Examples are low-carbon steel and titanium alloys.

With the second cutting mechanism, the material does not burn, but melts, and the gas jet removes the liquid metal from the cutting area. Such a mechanism is used for laser cutting of metals and alloys with a low thermal effect of the reaction of combustion, as well as those that result in the

interaction of oxygen with the formation of refractory oxides. Examples can be doped stainless and high-carbon steel, aluminum alloys.

A laser (optical quantum generator) is a device generating coherent and monochromatic electromagnetic waves of the visible range by forced emission or diffusion of light by atoms (ions, molecules) of the active medium [7].

Technological lasers are divided according to types primarily depending on the composition of their active medium.

Technological lasers are classified according to the following features:

- aggregate state of the active medium (gas, solid, liquid, semiconductor);
- pumping method (gas discharge, gas-dynamic);
- a temporary mode of generation (continuous, pulsed, pulsed-periodic);
- level of output power and operational characteristics.

The technological laser consists of three main nodes:

- sources of energy (mechanism or pump system);
- active (working) body, which is subjected to the pump, which leads to its forced radiation;
- an optical resonator (a system of mirrors), which ensures the intensification of forced radiation of the active body.

For cutting, solid-state lasers (Figure 3.3) and gas with a longitudinal or transverse gas flow are commonly used. In a solid-state laser chamber, a pumping lamp and an active body, Nd-Glass rod, doped with Ytterbium (Yb-YAG) or neodymium (Nd-YAG), are placed on the solid-state laser.

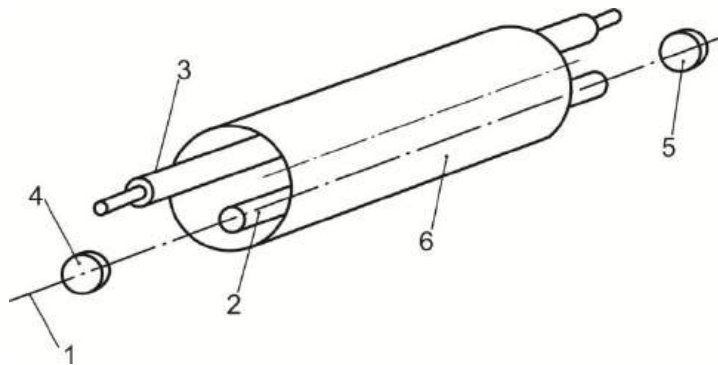


Figure 3.3 – Scheme of solid-state technological laser: 1 – laser beam; 2 – active body; 3 – pump lamp; 4 – partially transparent mirror; 5 – reflective mirror; 6 – lighting chamber

The pump lamp creates powerful light flashes to excite the atoms of the active body. At the ends of the rod are the mirrors of the resonator - partly transparent and reflective. The laser beam is amplified in the resonator due to multiple reflections inside the active body and goes through a partially transparent mirror.

In gas technological lasers, as an active body, a mixture of gases, usually carbon dioxide, nitrogen and helium, is used. In lasers with a longitudinal

pumping, a mixture of gases coming from cylinders, pumped through a gas discharge tube. The electrical discharges between the electrodes connected to the power supply are used for energy excitation of the gas. At the ends of the tube are placed mirror resonator, translucent and reflective. Gas lasers with transverse gas flow are more compact and powerful (Figure 3.4). Their output power may exceed 20 kW.

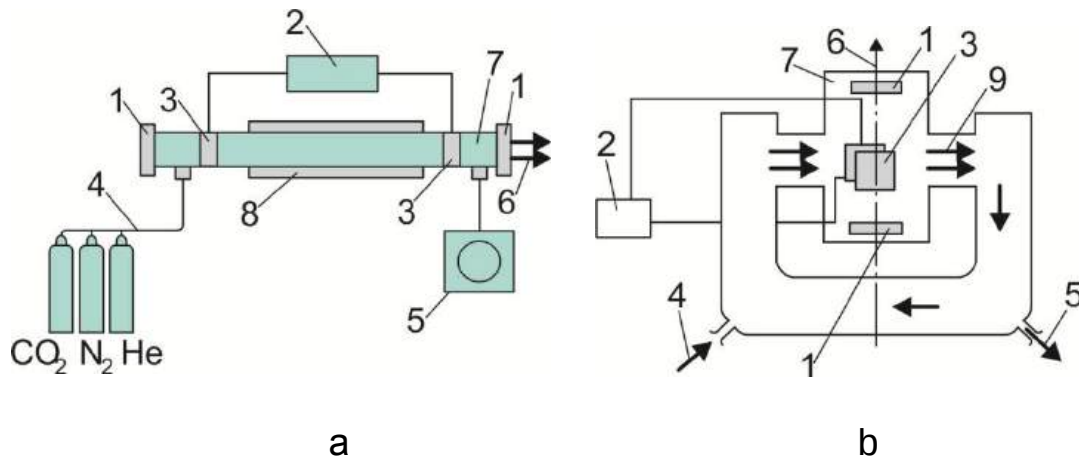


Figure 3.4 – Schemes of lasers: a – with longitudinal gas flow; b – with transverse gas flow (1 – mirror; 2 – power supply; 3 – electrodes; 4 – gas mix input; 5 – exhaust collector; 6 – laser beam; 7 – gas-discharge tube; 8 – cooling system; 9 – direction of gas flow)

Batch solid-state lasers have relatively low power, usually not exceeding 5 kW. The wavelength of laser radiation on neodymium glass and yttrium-aluminum garnet is 1060 nm. The radiation mode can be pulsed or pulsed-periodic.

Solid-state lasers poorly process nonmetals, since these materials are completely or partially transparent for radiation at 1060 nm, for example, plexiglas. The laser beam is more sensitive to the uneven surface of the treated material. However, in the separation of aluminum alloys, copper and brass solid-state lasers have an advantage over carbon dioxide, since the absorption of radiation by the surface of these metals is much higher in the wavelength of the solid-state laser.

Carbon dioxide lasers are more versatile, they are used to process almost all metals and nonmetals. In addition, a very low beam divergence allows the source of laser radiation to be placed outside the processing area without loss of beam quality.

Depending on the design features of the radiators, it is possible to implement a continuous or pulse-periodic laser cutting operation. Nowadays, the use of continuous lasers has become more widespread for the decomposition of sheet materials.

The technological laser as a source of powerful laser radiation that meets the specified technical requirements is a major component of laser process

equipment, although it is not used in industry.

Practically all domestic and foreign firms for sale are exhibiting not technological lasers, but laser technological installations and laser technological complexes.

Laser technological unit (LTU) is a technological laser with an external optical path and a set of external optics. In most cases, the LTU has a manipulator of products, the work of which is not related to the operation of the laser. LTU is intended mainly for the implementation of specialized technological operations. An example of this installation can be "Kharkiv-L" (CJSC "Institute UKRRGSTANKIMPROM", Ukraine). The plant uses industrial CO² - a laser Fanuc C4000E or RofinSinar with a power of 4 kW, where the sheets are cut from the structural steel in the thickness up to 20 mm, stainless steel - up to 12 mm, aluminum - up to 8 mm. The dimensions of the cut sheet are 1500x3000 mm.

National company Research and Industrial Center "Lasers and equipment TM" for many years have been successfully developing batch production of laser technological equipment of a wide range of new generation for cutting (ML3 and ML4).

The modern laser technological complex (LTC) is a complex automated system. LTC contains the following:

- devices of external optics, providing formation of a laser radiation spot, visual and parametric control of the process;
- systems of technological process binding and connection of LTC with other equipment in a single technological line;
- power supply, and control systems, cooling, pneumatic units.

The main parts are the laser and kinematic blocks (coordinate tables and drives, scanning systems, systems for tracking the details of the profile, etc.) necessary for the organization of moving parts and spots, as well as processing according to a given contour (drawing). In addition, modern LTC is impossible without the means of digital information processing and special software, which allows us to control the technological process, control and diagnostics of the components and the system in general.

In a number of applications, LTC has not only to provide automatic processing, management and quality control of process and product, but also be able to make decisions on its own and implement measures to ensure the required quality in case of deviation of technological parameters. Thus, the modern LTC embodies the achievements of many areas of high-tech production, and simultaneously the development of laser technologies largely determines the development of virtually all branches of modern industry [7].

The LTC model PLATINO-2040 of the well-known Italian company PRIMA INDUSTRIE uses a CO² laser and belongs to world-class products (Figure 3.5).



a



b

Figure 3.5 – LTC model PLATINO 2040: a – general view;
b – fragment of cutting

LTC, as well as most of the complexes of the company, has a monolithic structure, which employs all the nodes, actuators, control system, resonator. This complex is distinguished by the console arrangement of the transverse coordinate. It is intended for high-precision gas-laser cutting of sheet materials of wide spectrum in the thickness from 0,2 to 20 mm at high speeds. The installation is equipped with an automatic boot device, which allows us to minimize the time of loading and unloading the sheets.

The system of contactless autofocusing of the laser beam provides automatic change of the size of the focal spot and the position of the nozzle for continuous cutting of different materials in a wide range of thickness.

The main technical characteristics of LTC PLATINO-2040

The value of operating displacement along the axis:

- X = 4000 mm;
- Y = 2000 mm;
- Z = 150 mm.

Weight of sheet workpiece – under 1300kg.

Speed of movement in coordinate –under 110 m/min.

Linear displacement precision 0.001 mm.

Section width 0.2 mm.

Cutting roughness (Ra) 6.3 mm.

Range of laser radiation power 200...3000 W.

Smoke outlet consumption 3200 m³/h.

Weight 11500 kg.

Model of technological laser – CP3000.

Electricity consumption 67 kW.

Wavelength of the laser beam 10600 nm.

Modal mode of the laser beam – TEM00/01.

Consumption of auxiliary gas (oxygen) 20...70 l/h.

Consumption of compressed air 1800 m³/h.

Characteristic features of the gas-laser cutting process are as follows:

- the diameter of the focused beam is less than the diameter of the oxygen jet, which is usually 1–2 mm;
- laser cutting is carried out by an expanding beam, that is, the focal point is always located above the surface of the metal.

When cutting carbon steels it is necessary to strive to focus radiation in a smaller diameter spot to increase the density of power, but no more than the value at which at the selected processing speeds a gas mode of cutting occurs.

The cutting depth of stainless steels increases with a decrease in the diameter of the focusing spot while reducing the quality of cutting.

For titanium alloys, the same patterns are characteristic, but when the power density decreases as a result of changing the focusing conditions, a sharp decrease in the depth of the cutting of metal is observed. The maximum depth of a well-executed cutting in this case corresponds to cutting speeds within 1.5–2 m/min.

Along with the power density an important technological parameter is the cutting speed. Increasing the speed of laser cutting results in improved cutting quality. This is due to the fact that when the rate of cutting is increased, the metal overheats less, which leads to a decrease in the depth of the changing layer and holds back the growth of the burr.

However, the variation in processing speed has its own limitations. The lower limit of the permissible cutting speed of practically all processed materials is a sharp deterioration in the quality of the surface of the section. In the conditions of cutting metals with a laser power of 1000 W, this phenomenon is especially characteristic at treatment speeds below 0.3 ... 0.5 m/min. A sharp drop in the thickness of the cut material corresponds to too high cutting speeds. Therefore, usually the speed of laser cutting does not exceed the range of 6...8 m/min.

The quality of the gas-laser cutting of sheet materials is estimated by the following parameters: width of the cut, surface roughness, presence of a burr, non-perpendicularity of the cutting edges, width of the zone of thermal impact (ZTI).

A lattice is formed on the lower edge of the cutting surface, which is easy to obtain at optimal gas-laser cutting modes. When deviating from the optimal modes of gas-laser cutting, mechanical impact is required to remove the burr even before milling the edge. The dimensions of the burr are checked on the

metallographic slabs. The surface of the section is characterized by the presence of two zones with different roughness. The first zone is located at the entrance to the metal and has a minimum roughness, the second zone is behind it and has a large roughness. The difference in roughness is the more significant, the greater the thickness of the cut metal. The macro-relief of the section of the surface is characterized by the height of the protrusions and the step between them.

The technological parameters of laser cutting of some materials are given in Table 3.3.

Table 3.3 – Technological parameters of laser cutting of materials

Material	Parameter				
	Power of laser radiation, W	Sheet thickness, mm	Cutting speed, m/min	Section width, mm	ZTI width, mm
Aluminum alloy	900	0.5...5	5...0.5	0.15...0.5	0.2...0.4
Structural carbon steel	350	0.5...5	5...0.5	0.2...1	0.2...0.23
Stainless steel 12X18N10T	350	0.5...5	3...0.3	0.2...0.6	0.1...0.2
Titanium alloy	350	0.5...5	5...0.5	0.5...1	0.3...0.5
Stainless heat-resistant steel					
VNC-2	800	1.5	3.4	0.25	0.15
CN-3	800	2.5	1.6	0.4	0.25
ZhC-6	800	3.0	1.1	0.3	0.15
EI-602	800	1.0	2.3	0.3	0.15

On the metallographic slabs check the cutting angle is formed by a perpendicular to the sheet and a straight line passing through two points at the ends of the section. The maximum allowed cutting angle should be no more than 7°.

The length of the ZTI is evaluated by the metallographic control of the cross section of the sample after pickling. In controlled size apart from the actual ZTI also includes a site with molten metal. The largest size with the angle of cutting is taken. Cracks in fused metal and ZTV are not allowed.

At the entrance of the laser beam, the depth of the oxidized layer is minimal and depends little on the change in cutting speed. With an increase in the depth of cutting there is a slight increase in the depth of the oxidized layer.

Compared with traditional methods, laser cutting has a number of undeniable advantages:

- laser cutting has no mechanical influence on the material processed;
- focused laser radiation of regulated power is an ideal tool that provides a qualitative smooth surface of the cutting edge of any material, regardless of its thermophysical properties;
- the accuracy of the positioning of the laser head is 0.08 mm, due to which the high accuracy of the mutual arrangement of the elements of the workpiece is achieved;
- the use of laser cutting is possible on easily deformable and non-rigid parts;
- due to the high power of laser radiation, high productivity of the laser cutting process is ensured;
- the possibility to get a qualitative section that does not require further additional processing;
- the ability to make products of any complexity in any kind and practically from any material.

The advantages of the method include the ability to automate the processes of cutting sheet materials which is the most mass-oriented processes of aviation production, increasing the coefficient of material use and reducing the timing of preparation.

3.2.2 Hydroabrasive cutting

Hydraulic cutting (water jet) is a kind of cutting, in which the material is processed by a thin super-speed jet of water. Hydro-abrasive cutting to increase the destructive power of a water jet is added with particles of high-solid abrasive material.

If ordinary water is pressurized to about 4000 MPa, and then passes through an aperture of less than 1 mm in diameter, it flows at a rate that exceeds the sound speed by 3–4 times. Directed to the processed product, such a jet of water becomes a cutting tool. With the addition of abrasive particles, its cutting capacity increases tenfold and it is able to cut almost any material.

The technology of hydroabrasive cutting is based on the principle of erosion of abrasive and water jet. Their high-speed solid-phase particles are energy carriers and, heating against the product parts, they tear off and remove them from the cavity of cutting. The rate of erosion depends on the kinetic energy of the active particles, their mass, hardness and impact strength, as well as the mechanical properties of the material processed.

Water pumped by a pump to super-pressure of about 100 ... 600 MPa is fed to the cutting head (Figure 3.6).

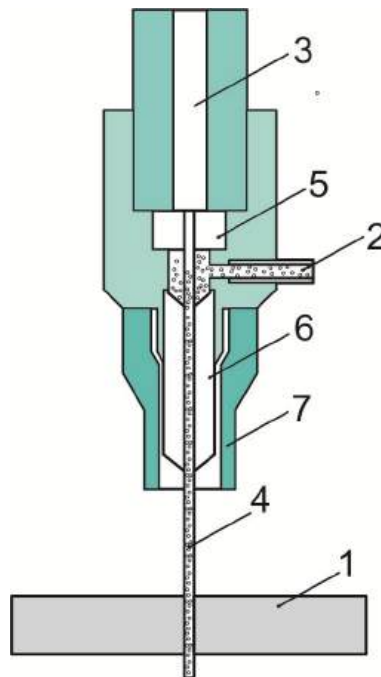


Figure 3.6 – Scheme of the cutting head for hydroabrasive cutting:
 1 – cutting material; 2 – abrasive feed; 3 – water supply under high pressure;
 4 – cutting water jet with abrasive; 5 – nozzle; 6 – mixer; 7 – casing

When breaking through a narrow nozzle (duct) usually in the diameter of 0.08 ... 0.25 mm with near-sonic or supersonic velocity, a stream of water enters the mixing chamber, where it is connected with particles of abrasive - garnet sand, grains of an electric corundum, silicon carbide or other high-solid material. A mixed jet exits the mixer with an internal diameter of 0.5 ... 1.0 mm and cuts the material. To extinguish the residual energy of the jet, a water layer with thickness of 0.7 ... 1.0 m is used.

With hydraulic cutting (without abrasive), the scheme is simplified: water under pressure is pulled out through the nozzle and goes to the cut product. The destructive power of a jet during hydroabrasive cutting is created to a greater extent due to the presence of abrasive, and water performs predominantly transport functions. The size of the abrasive particles is chosen to be equal to 30 ... 40 % of the diameter of the cutting jet, to ensure its effective impact and stable process completion. Usually the size of the grains is 0.15...0.25 mm, and in some cases - about 0.075 ... 0.1 mm, if it is necessary to get a cut surface with a low roughness. The choice of abrasive depends on the type and hardness of the cut material. It should also be taken into account that the harder abrasive wears off the nodes of the cutting head faster.

The nozzles are usually made of sapphire, ruby or diamond. The service life of sapphire and ruby nozzles is up to 100 ... 200 hours, diamonds - up to 1000 ... 2000 hours. Mixing tubes are made of high-strength alloys, their service life, as a rule, does not exceed 150 ... 200 hours.

The cutting speed (the speed of movement of the cutting head along the surface of the product) significantly affects the quality of the cut. At high speed there is a deviation of the hydroabrasive jet from the straight line, and also markedly weakening the jet as the cutting material. As a consequence, the incision of the cut increases and its roughness increases. Cutting can be performed at a maximum speed of 80 ... 100 %. Qualitative cutting usually corresponds to a speed range of 33 ... 65 %, fine cutting – 25 ... 33 %, precision – 10 ... 12 % of maximum speed.

Some models of cutting heads, for example, Dynamic Waterjet of the American company Flow International Corporation, use the technology of automatic compensation of taper. Compensation comes as a result of programmed controlled dynamic slope of the cutting head at a certain angle. This allows us to increase the cutting speed while maintaining its cut quality and, accordingly, reduce production costs.

With the decrease in the internal diameter of the mixer (under other identical conditions), the productivity and precision of cutting increase, the thickness of the cut decreases (it is approximately 10 % more than the internal diameter of the mixer). However, this also reduces the service life of the mixer. During operation, its internal diameter is increased by about 0.01 ... 0.02 mm for every eight hours of operation. And when it becomes too large, the pump cannot maintain the sufficient pressure required to ensure efficient cutting.

The consumption of abrasive material depends on the ratio of the diameters of the mixing tube and nozzle, the conditions of cutting and other factors. The maximum working fluid pressure is usually 300 ... 320, 380, 415 or 600 MPa. The higher the pressure, the higher the speed and efficiency of cutting. At the same time, the cost of operating equipment increases.

Equipment used for hydroabrasive cutting, is characterized by varying degrees of universality and automation, and can be made in the form of robotic systems.

The structure for hydroabrasive cutting usually consists of the following:

- high pressure pump;
- a cutting head (one or several);
- a coordinate table with actuators of displacement of cutting heads;
- high pressure wiring;
- abrasive feed system;
- numerical control system.

In addition, the listed composition of a specific unit may include a number of devices and systems for performing individual functions, related to the specifics of the unit and demands of the "customer."

The high-pressure pump of the water-jet cutting system provides the creation of a supersonic fluid jet. The vast majority of currently used hydraulic cutting systems use multiplier power supplies. A universal principle hydraulic circuit of a pump is developed, where as a pressure amplifier a special multip-

lier of bilateral or one-way action is used. The layout selection depends on the specific treatment conditions (for example, from the allowable value of the pressure drop, the required flow rate of the liquid), which allows us to achieve the desired results on both the productivity and the quality of the cutting. In addition, standard adjustment, distribution, control and auxiliary control devices are used.

The cutting (jet) head (see Figure 3.6) carries out the final formation of a high-pressure jet as a cutting tool. There are many jet heads for hydroabrasive cutting of metals, which objectively testifies to the variety of operational requirements, and at the same time - the lack of optimal structures.

The coordinate table with drives provides the location of processed products in the working area and the positioning of the cutting heads. Its composition usually includes a bath for receiving a hydroabrasive jet and waste treatment. The water that merges from the bath enters the tank, where it is cleared of sludge - used abrasive and small waste of cut material.

High pressure water is fed from the pump to the cutting head by a system of movable and fixed pipes. To ensure the density of the joints, when using the portal and the working head, special high-pressure hinges or spiral tubes of high pressure are used.

To apply abrasive to the cutting head, a vacuum system operating on the principle of a spray or a pressure-operated device is used. In this case, the system consists of a pressurized abrasive bin, a dosing and abrasive mechanism provided by the mini tanker, as well as flexible connecting hoses.

With the aid of a hydroabrasive jet, one can cut almost any material. In this case, there are no mechanical deformations of the workpiece (since the impact force of the jet on the cutting piece is only 1 ... 10 H), nor its thermal deformation, since the temperature in the cutting zone is about 60 ... 90°C. In comparison with thermal treatment technologies (oxygen, plasma, laser, etc.), hydro-abrasive cutting has the following distinctive advantages:

- higher quality of cutting due to minimal thermal impact on the workpiece (without melting or burning edges);
- the possibility of cutting thermosensitive materials (fire and explosive, laminated, composite, etc.);
- the ability to cut down sheet materials in batch mode;
- the possibility of cutting different materials in one installation, because in the presence of the necessary software operator it is enough to type the material, thickness and speed of cutting and the machine cuts the specified material;
- ecological purity of the process, complete absence of harmful gas emissions;
- explosion and fire safety of the process.

Hydroabrasive cutting can be performed on a complex contour with high accuracy (up to 0.025 ... 0.1 mm), including for the processing of volume products. Its usage enables chamfering. Hydroabrasive jet is effective in cutting materials such as titanium alloys, heat-resistant alloyed steels, various types of high-strength ceramics, composite materials. This technology is irreplaceable in case of cutting various sandwich designs (materials consisting of glued layers of various materials, including soft, alternating with super-hard).

The disadvantages of hydroabrasive cutting include:

- substantially less speed of cutting of steels and titanium alloys of small thickness in comparison with plasma and laser cutting;
- High cost of equipment and high operating costs (characteristic for laser cutting) due to the consumption of abrasive materials, electricity, water, replacement of mixing tubes, water nozzles and sealing elements that withstand high pressure, as well as expenses for waste disposal;
- increased noise due to leakage of a jet with supersonic velocity (also characteristic for plasma cutting).

3.3 Formation of sheet parts from hard-to-form materials with heating

When choosing the most suitable technological processes of forming parts, it is necessary to take into account the behavior of sheet materials during deformation, and the features of phase transformations in these materials.

Stainless high-strength steel BHC-2 of martensite class under normal conditions is stamped unsatisfactory. Therefore, for the manufacture of complex parts, heating is required with subsequent normalization. Heating up to 950 °C and subsequent cooling cause significant leaks, which are difficult to eliminate by further refinement due to high resistance to deformation. For this steel, the most effective technology is the combination of heating for hot pressing heat treatment.

The peculiarity of the steels of the transition class (CH-3, etc.) is that after hardening for strengthening (940 °C) they do not form a martensitic structure at room temperature and have a satisfactory plasticity. The parts have significant deformations appeared (leaks from quenching), which are eliminated by the following processing. After normalization (1050 °C), these steels have high technological characteristics: 18 %, 900 MPa.

Figure 3.7 shows that the intensive formation of the martensitic structure begins at a temperature of 100 ... 120 °C and ends at 20 ... 40 °C.

The analysis of the growth of the martensitic structure (Figure 3.7, b) shows that the details of the steels of this group can be stamped in any way, but when stamped, the martensite is rapidly deformed, which leads to strengthening of the steel, and therefore the best stamping with the combination.

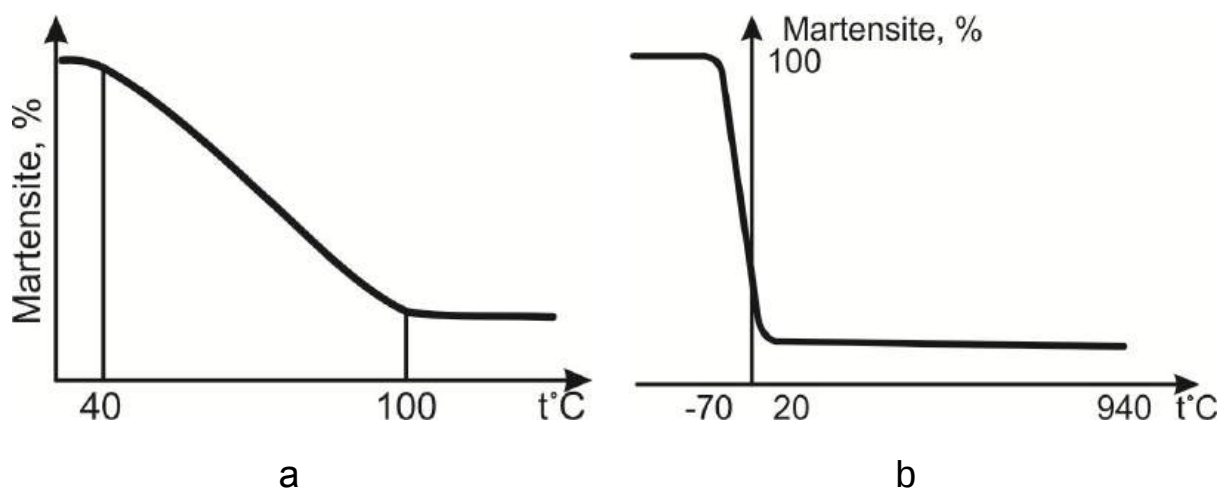


Figure 3.7 – Graphs of the content of martensite depending on the temperature: a – steel BHC-2, b – steel CH-3

Steel EI878, EP654 and other steel of austenitic class heat treatment are not strengthened. To restore plasticity they are heated, and then the values of these steels reach 35 ... 40 %, 550 ... 850 MPa.

When stamping the resistance to deformation quickly increases, so for parts of complex forms it is necessary to provide several transitions with interoperative heating to increase the plasticity.

The optimum technology for manufacturing parts from these materials is stamping by elastic media on presses type P5650, P5450, QAB-31.5. The introduction of such equipment allows us to realize the technology of seamless manufacturing of parts of a large nomenclature, including a complex form. The possibility of stamping parts in lead-zinc stamps on sheet stamping hammers and electro-hydraulic presses is not excluded. In both cases, the high qualification of the stamper is required.

Titanium alloys OT4, BT20 and others belong to hard-to-deform materials. The radii of bending, for example, for VT20 are allowed to be at least 7–9 thickness of the material, the angle of the spring is up to 20°, and the distribution of results in this angle is very large, therefore increasing the accuracy of details by improving the equipment on the angle of the spring is almost not effective. The most optimal for these alloys is the technology of manufacturing parts with heating, since the plasticity depends more heavily on the temperature of the heating and the rate of deformation.

Thus, along with the formation of sheet parts in a cold state, processes with heating of blanks are widely used. Sheet punching at elevated temperatures can dramatically reduce the resistance of the deformation material and increase the plasticity. Punching with heating increases the accuracy and quality of parts, almost completely eliminates the need for reference work, allows us to eliminate the difficulties that arise in connection with the development of the production of new products.

Furthermore, some technological processes of stamping with the heating of deformable workpiece, which are most successfully used in the formation of parts of low-plastic materials, are considered.

3.3.1 Dynamic punching on heat-treated hammerheads

Punching by elastic media of cold-finished parts from high-strength stainless steels is usually performed on modern presses P5650, P5054 with a working pressure up to 100 MPa. The press for a deep extract QAB-31.5 provides a maximum pressure up to 125 MPa. However, even such high working pressures do not guarantee complete provision of the parameters of the entire range of parts. Some parts made of low-alloy steels may require a very costly further refinement. Titanium alloys are almost not stamped. Therefore, parts made of low-plastic stainless steels, which are not subjected to rough seaming, are cold, whereas titanium alloys are stamped with the heating of the workpiece.

Punching of heated workpiece is carried out on a hammer at a speed of movement of a container filled with polyurethane, no less than 1.0 ... 1.5 m/s. The choice of hammer equipment is due to the need to minimize the contact time of an elastic medium with a heated mold. Applied as an elastic polyurethane tool, it withstands compression pressure up to 200 ... 300 MPa, which is 5-7 times higher than that of rubber.

Dynamic stamping by an elastic medium on a hammer [4] is realized in a complex with the device URNK-4 for radiation heating. The heating panel of the plant has 138 quartz lamps and provides heating of the workpiece with dimensions up to 750x1000 mm to a temperature of 800°C, 1000°C and above. Heating time varies from 0.5 to 2.0 minutes. The input and output of the heating panel is blocked with the container's movement so that at the moment of lowering the container (working stroke) the panel automatically leaves the stamping zone.

A similar scheme for the formation of parts of low-plastic materials can be constructed using stamping complexes based on high-speed presses (electric and hydrodynamic with a container speed of 1.5 m/s or more). Unlike hammer, these presses allow the pressure in the container to be dosed depending on the complexity of the parts and deformation transitions.

3.3.2 Combined punching

The most promising way of increasing the productivity and quality of the manufactured parts is combined punching. Punching, combined with high-temperature heat treatment, has been widely used in the manufacture of components of complex form from steels of martensite and transitional austenitic-martensitic classes. Nowadays, almost all nomenclature of parts of steels BHC-2 and CH-3 at aircraft manufacturing plants is made in the mode of combining operations.

Formation of these parts by cold stamping was carried out in two transitions on sheet stamping holes with intermediate annealings, removal of lead and zinc traces and de-oiling. After punching, the reinforcing heat treatment was carried out, which led to distortion of the parts, and there was a need for calibration and manual processing.

In order to increase the accuracy and reduce the cycles of manufacturing parts, the principle of combining heat for heat treatment with heating for forming is applied. After high-temperature heating the workpiece is transferred to the furnace, the temperature of which corresponds to the upper limit of the temperature interval of stamping of certain grades of steels. The time between the unloading of the workpiece from the furnace and the stamping must not exceed 30 ... 40 s, whereas the temperature must not exceed the lower limit of the temperature interval of stamping.

Cyclograms of combined stamping of CH-3 and BHC-2 steels are shown, respectively, in Figures 3.8 and 3.9 [4].

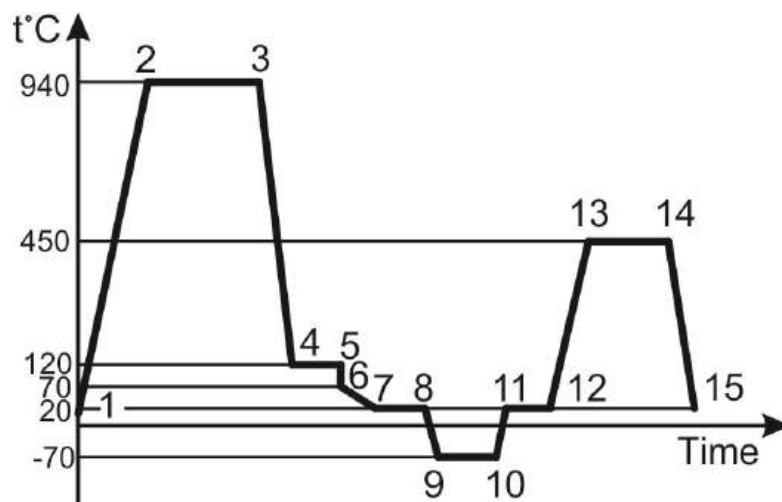


Figure 3.8 – Cyclogram of combined stamping of parts of steel CH-3 with heating for heat treatment: 1, 2 – heating under austenisation; 2, 3 – holding for austenisation; 3, 4 – partial cooling; 4, 5 – holding in a drive; 5.6 – punching; 6.7 – air cooling; 8, 9, 10, 11 – cold treatment in the device; 12, 13, 14, 15 – aging

To exclude distortion of parts with CH-3 caused by phase transformations in steel, their treatment with cold is performed in the position fixed in special devices. For the same purpose, it is advisable to cool parts with BHC-2 after pressing from a temperature of 120 °C to a room temperature in a closed die.

Subsequent aging at a temperature of 450 °C practically does not lead to distortion of parts. It should be noted that for the widespread introduction of this technology it is necessary to have heat-resistant elastomers that do not lose their properties to temperatures at 350 ... 450 °C.

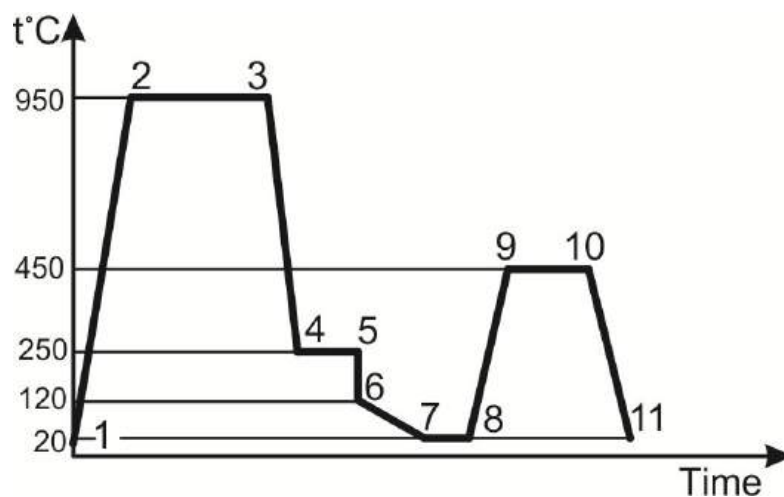


Figure 3.9 – Cyclogram of combined stamping of parts of steel BHC-2 with heating for heat treatment: 1, 2 – heating for heat treatment; 2, 3 – holding for austenisation; 3, 4 – partial cooling; 4, 5 – holding in a drive; 5, 6 – punching; 6, 7 – cooling; 8, 9, 10, 11 – aging

Combined punching is used in the manufacture of titanium alloy parts, in particular in the implementation of a complex of work on the development of technology for the combined punching of parts from the alloy VT-23 [1]. In this case, the combination of operations not only excluded the quenching and aging, which significantly reduced the cycle and the complexity of manufacturing, but also allowed a combination of temperature modes of stamping to adjust the mechanical properties of parts.

For the implementation of combined stamping of parts of titanium alloys of type BT-14 and BT-16, i.e. alloys with the critical cooling rate higher than the speed of cooling in the air during quenching, a special machine has been created. It consists of two presses - isothermal and hot stamping, connected in a general cycle of work by a mechanical arm [5]. The part stamped on the press at tempering temperatures, automatically, with the help of a mechanical arm, is transferred to the working area of the hydraulic press hammer and cooled in a fixed position with subsequent pre-calibration blow. At the machine, one can make parts of a coat size of 300x600 mm.

3.3.3 Formation with thermofixation

In the case of titanium alloys, this process is based on the use of a significant increase in the velocity of creep and relaxation of stresses in titanium alloys when heated to temperatures of 500 ... 550 °C, in which the elastic deformation passes into plastic and is carried out according to the modes of complete annealing in the device.

The creep can be characterized as a slow increase in the plastic deformations of the material under force influences smaller than those that can cause residual deformation in tests of normal duration. Creep is characteristic of al-

most all structural materials. For steels and titanium, creep is significant only at elevated temperatures (over 300 °C) and proceeds more intensively, the higher the temperature. In materials with a low melting point (lead, aluminum, etc.), the creep is quite noticeable at room temperatures.

Creep is accompanied by stress relaxation. Relaxation (weakening) is the process of gradual transition of the thermodynamic system from a nonequilibrium state caused by external influences to the state of thermodynamic equilibrium. An example of relaxation processes is the relaxation of stresses - the gradual change in the stresses in the metal with its constant deformation.

Thus, for the realization of the process of heat-fixing, the part is laid in the device, securely clamped (fixed) therein and loaded into a furnace heated to a temperature of 500 ... 550°C (for titanium alloys). After the endurance in the furnace the device is unloaded and the part is cooled along with the device.

Appliances for the realization of the processes of thermal fixation can be single or group, made of metal or non-metallic materials. However, in any case, the applied device should have its own rigidity and provide reliable fixing of the parts. In most cases, fixation of parts in the device is performed in the bases located in the assembly devices.

The technological process with the use of thermal fixing is used to preserve the shape and geometric parameters, increase the accuracy, as well as form the preformed parts.

To preserve the shape and geometric parameters of the pre-stamped parts, heat-fixation is used for the treatment of high-strength steels of the transient (austenitic-martensitic) class of CH-3 in the process of cooling. At a processing temperature of 70 °C, the distortion of the parts caused by phase transformations in the steel occurs. To avoid this, these parts are treated with cold in a rigidly fixed position in special devices.

3.3.4 Isothermal punching

Isothermal deformation differs from conventional processes of hot stamping by the fact that the heated mold is subjected to deformation in a die heated to a deformation temperature [1].

Isothermal punching of sheet metal parts from titanium alloys and high strength steels used in domestic aircraft engineering is very limited nowadays due to the difficulties in creating presses for isothermal deformation and stamping equipment.

In foreign practice, in the case of isothermal punching of small parts (up to 1000x800 mm), specialized presses equipped with slabs are used. In a special chamber a neutral atmosphere is created in the heating zone [2].

In some enterprises [4] isothermal punching of parts such as fenders, diaphragms, walls of titanium alloys OT4-1, BT-20 with overall dimensions of 600x500 mm takes place on ordinary hydraulic presses with little effort and

precise adjustment of this force and the course of the slider. In this case, a stamping block is used, which is an electric furnace with a matrix installed on the bottom, and the upper movable sealing is performed by a punch. The stamp is ceramic. The heating elements are located through holes of the matrix and the punch. The control and maintenance of the optimum deformation temperature is carried out automatically with the help of thermocouples, concentrated in the center of the stamp, and potentiometers. In this block, parts are formed with a relatively complex engraving.

For the technological support of isothermal punching of sheet metal parts and other forming processes at elevated temperatures, a complex of equipment has been developed in a multi-plunger hydraulic press PGFK 1200\90-120\75, a furnace for preliminary heating of equipment and a two-way gear coordinator [1].

Hydraulic multi-presser can produce sheet parts in overall dimensions up to 1200x900 mm and depths up to 350 mm from the whole range of high-strength titanium alloys and structural steels. The presence of additional (except vertical) horizontal force and marker device allows us to make parts of various forms. The press works in a semi-automatic mode and can be used both for thermal calibration of the pre-stamped (for example, elastic medium) parts, and for the shaping of parts from flat workpiece in creep mode. The equipment is completed on special removable tables, is warmed up by a given thermal cycle (which excludes distortion of the equipment during heating) and is automatically installed in the working area with the help of a special device mounted in the press.

When implementing processes of isothermal punching and other processes associated with high-temperature heating of the workpiece, the critical role is assigned to heat-resistant technological equipment. Such fixtures from glass-ceramics have been developed by Research Aviation Institute together with the Institute of Technical Glass for shaping sheet metal parts. It is designed for stamping with operating temperatures up to 1000°C and is manufactured using cold slip casting method on wooden or plaster models. A special glass ceramic does not shrink during hardening and provides high purity of the surface of the stamp. The cost of ceramic stamps and the complexity of their manufacture is much less than the metal snap-off, which is used in the billet and stamping workshops of the industry. Stamps from glass-ceramic are used in the manufacture of sheet metal parts of titanium alloy BT-20 on a number of experimental and batch plants [1].

It should be noted that ceramic stamps have sufficient compressive strength, but have low bending strength, which means they are fragile. Therefore, the increased requirements relate to the accuracy of the performance of the surface of the stamps, to ensure the rigid fixation of the matrices and punches relative to each other.

3.3.5 Formation in the state of superplasticity

One of the promising directions of intensification of sheet punching operations is the application of the superplastic effect. Superplasticity is the ability of materials to stretch under certain temperature-speed conditions to accept rather significant deformations without destruction exceeding their values under ordinary conditions of the test several times.

The state of superplasticity is determined by a set of features: the increased sensitivity of the stress of the flow of superplastic material to the change in the velocity of deformation, or, in other words, to rapid strengthening; slight deformation strengthening; abnormally high resource of deformation ability; the current of the metal in the state of superplasticity, which is several times lower than the yield strength, which characterizes the plastic state of the material.

The most significant of the listed signs is the first one, while the rest to a certain extent can be considered as its consequences. Strengthening, deformation and high-speed (Figure 3.10), has a great influence on the mechanism of deformation; in particular, it contributes to the alignment of deformations, the steady flow of the process.

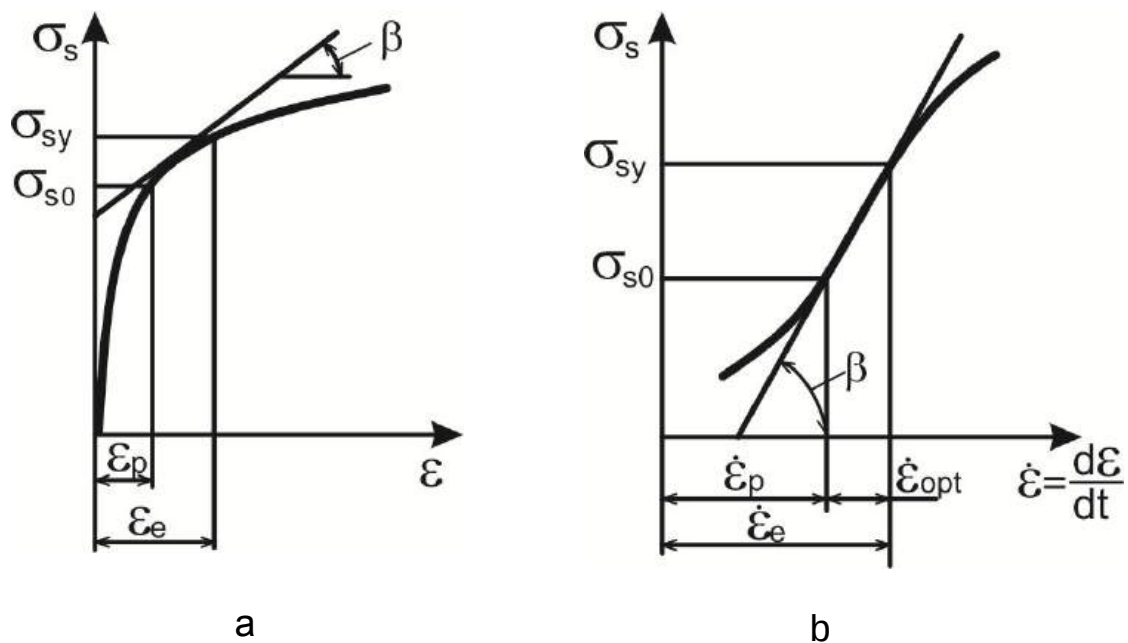


Figure 3.10 – Diagrams illustrating the strengthening of metal during plastic deformation: a – deformation; b – high-speed

No significant deformations can be achieved as a result of the positive effect of strain hardening, because its intensity increases with deformation and cannot restrain the deformation localization (Figure 3.10, a). In deformation with heating prevailing anti-stressing processes; the strengthening of the metal is

negligible or absent altogether. However, the high-speed strengthening acts as a stabilizing factor (Figure 3.10, b).

The best efficiency can be ensured by the range of velocities of deformation in which the angle β of the tilt is tangent (see Figure 3.10, b) to the strength curve, which characterizes the intensity of high-speed reinforcement, and has the greatest value. For some metals, this range is rather narrow and lies within low strain rates.

In contrast to deformation strengthening, high-speed hardening depends slightly on the deformation value, which makes it possible to obtain an extremely high degree of uniform deformation during stretching.

Superplasticity is detected in certain temperature-speed conditions of deformation of metals, characterized by a special structure. Depending on the structure of the source material, two types of superplasticity are distinguished: metals and alloys with particularly fine equilibrium grain, resistant to growth at deformation temperature, and polymorphic metals and alloys deformed during phase transformations, when the initial grain size does not matter.

Recently, the processes of stamping in the state of structural superplasticity (first kind) have become common, therefore the following features belong to these processes.

The temperature interval of structural superplasticity is quite wide, varying for different materials. It can range from the temperature of the beginning of recrystallization (0.4 melting temperature) to temperatures close to the melting point. The lower limit of the interval is due to the important role of diffusion processes in the mechanism of deformation of fine-grained materials. The upper limit corresponds to the temperature of the beginning of the combined recrystallization. However, whatever the temperature of the superplasticity, it must be maintained constant over the volume of the deformed object throughout the deformation period to ensure a uniform flow of metal. Therefore, structural superplasticity is sometimes called isothermal.

For the vast majority of metals and alloys, the optimal range of deformation rates corresponding to structural superstructure is $10^{-2} \dots 10^{-5}$ 1/s, that is, in the interval between the speeds of high-speed creep and strain rates used in traditional stamping processes.

A number of features characterizing the behavior of materials in the state of superplasticity, on the one hand, extremely high deformation ability, low resistance to deformation, insignificant influence of the superplastic deformation on the microstructure, high relaxation ability provide the possibility of a significant increase in the efficiency of the processes of the superplastic forming of parts and quality of finished products. On the other hand, small deformation rates and their maintaining at the level corresponding to the state of superplasticity, the need to prepare the structure of the dies and the regulated tempera-

ture regime of deformation significantly complicate and increase the technological preparation of production, reduce the productivity of processes and as a result limit the use of superplasticity in production.

Comparison of these advantages and limitations, as well as generalization of the existing experience of superplasticity in stamping processes, leads to the need to select the most desirable options for using this technology, which would provide the maximum effect.

Punching of low-plastic and hard-deformable steels and alloys on the basis of nickel, titanium, refractory metals, which differ, as a rule, by high cost, characterized by extensive and multiple operations. Therefore, an increase in the deformation ability in the state of superplasticity of these materials will significantly increase the deformation in one technological transition and switch to a low-operational technology, which largely compensates for the decrease in productivity due to low strain rates.

The use of the superplasticity effect in sheet stamping allows the processes to be carried out without the use of presses. The necessary efforts of deformation can be created by vacuuming the cavity of the matrix and with a slight excess pressure on the workpiece.

When shaping parts under the pressure of the gas medium, maintaining the constant rate of deformation in accordance with the regime of superplasticity is achieved by constant regulation of the pressure of the forming gas during the process flow. Preliminary calculation of the load curve is carried out, the dependence of pressure formation on time. The basis of the calculation method should be the principle of ensuring a controlled rate of deformation of the workpiece, which receives the maximum degree of deformation.

Implementation of superplasticity capabilities in sheet stamping operations at certain gradient deformations, stresses, pressures, deformation rates causes large variations in the thickness of the parts, as the deformation occurs solely by the freeing part of the workpiece without moving the flange, whereas the deformation degrees are very important.

This defect can be partially eliminated by adjusting the temperature field (in the allowable range), the pressure field, and preliminary preparation of the structure of the workpiece. Worthy of note is also the method of reverse formation, in which the sheet blank initially breaks out into the cavity opposite the cavity of the matrix, to a height that is larger than the shape requirements. Then the pressure is fed to the opposite cavity to form the billet into the matrix and obtain the final form.

For the successful implementation of superplastic deformation, the circuitry of the load, which should ensure the uniformity of the stress field, becomes important. To analyze the possibilities of different load schemes, a machine was created for the manufacture of parts of complex shapes with overall di-

mensions of 500x500 mm [1]. The machine works at excessive pressure up to 0.6 MPa according to the technological schemes shown in Figure 3.11.

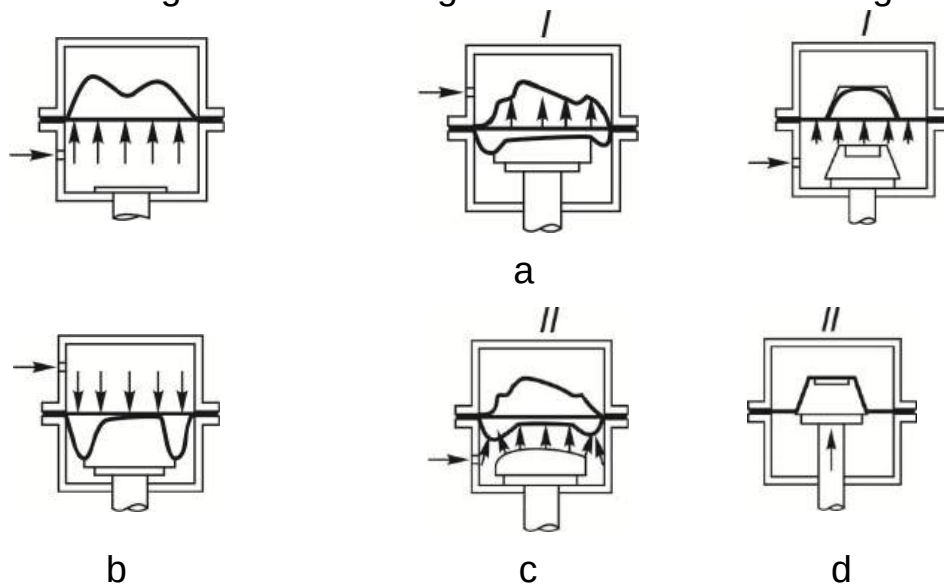


Figure 3.11 – Technological schemes of forming in superplastic modes: a – free blowing in the matrix; b – free stamping punch; c – reversing blowing with a set of material in two stages; d – combined stamping in two stages

For the manufacture of large-sized sheet parts such as a reinforcing wall, sheets of titanium alloys of high strength (VT20, etc.), the method of gas-vacuum stamping [4] is used. According to this method, a technological package of two hermetically welded perimeter dies with an internal arrangement of the sheet matrix and a vacuumed inner cavity of the dies is loaded into the working space of the electric furnace (Figure 3.12), which is equipped with a special container with a neutral medium (argon).

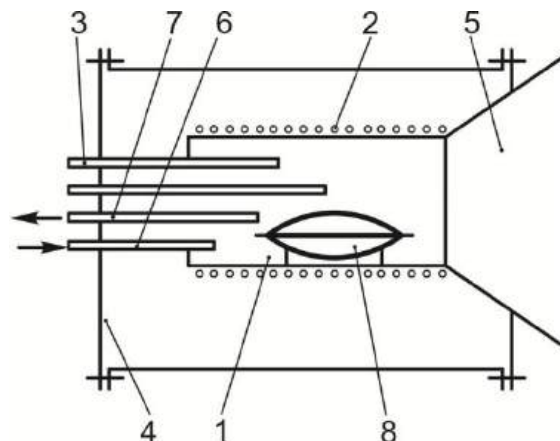


Figure 3.12 – Principle diagram of compression furnace: 1 – camera; 2 – heater; 3 – thermocouple; 4 – body; 5 – cover; 6 – channel for feeding argon; 7 – channel of the vacuum system; 8 – matrix workpiece

Deformation is carried out in the given temperature-speed modes, which correspond to the state of superplasticity. The stamping process can be imple-

mented according to one of the technological schemes: deformable forces can be atmospheric pressure (gas-stamping) or excess pressure (gas-compression stamping).

For punching, a lightweight sheet of matrix made of heat resisting steel of VZh-101 type is used, the material capacity and the complexity of its manufacture is almost 100 times lower than the monolithic equipment, which is usually used for hot stamping.

Very small metal thickness of sheet equipment compared with monolithic allows sharp reduction of the cycle of heating and cooling of the sheet matrix. The presence of protective containers reduces the temperature gradient when cooled and allows cooling process of bags directly under the influence of stamping operating temperatures. The facing of the inner surfaces of the container with sheets of titanium alloys contribute to the obtaining of parts with maximum surface cleanliness. After stamping, the products do not need to be etched. To prevent diffusion bonding of the workpiece material with a matrix, a separating layer is created, and lubricant is applied. Boron nitride, which is resistant to a temperature of 1000°C, can be used as a separating layer.

High-volume titanium parts with complex relief are manufactured by the method of gas-stamping. The duration of the formation process depends on the complexity of the relief, values of deformable pressures.

The intensity of the process with increasing working pressures increases significantly. It increases productivity and expands the process of rigidity of the product being formed, relief, thickness of sheet parts, grades of materials. In this case, the stamping modes of the particular parts must correspond to the temperature-speed interval of superplasticity.

3.3.6 Formation in the mode of superplasticity and diffusion welding

In this case, the superplastic formation of titanium is used in combination with diffusion welding, which is a connection of parts under pressure at a certain temperature, and the connection occurs without melting the material and the use of soldering. In titanium alloys, both processes occur under identical conditions with respect to temperature and pressure, which causes their association. The process [2] developed and patented by the specialists of Rockwell (USA), which combines superplastic formation and diffusion welding, makes it possible not only to form complex metal structures from sheet materials but also to connect them to components of the power circuit, performing simultaneously strengthening, edging, joining of fastening units.

Figure 3.13 shows the scheme of the use of superplastic molding and diffusion welding in the manufacture of the assembly of the aircraft.

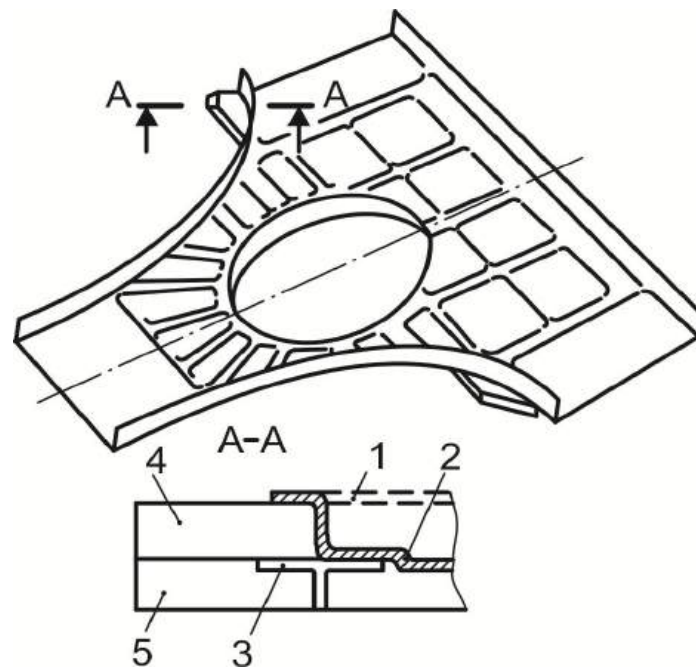


Figure 3.13 – Scheme of application of superplastic and diffusion welding:
 1 – sheet workpiece; 2 – molded diaphragm; 3 – pre-installed parts;
 4 – matrix; 5 – filler

In this case, the position of the pre-installed parts 3 determines the filler 5, made in accordance with the geometric parameters of the molded node. The sheet blank 1 and the diaphragm 2 are mounted on the matrix 4. The heating of the equipment is carried out with the help of ceramic heating elements. The pressure required for the formation of the diaphragm and the diffusion welding with parts 3, is created by argon. The temperature-velocity conditions of forming must correspond to the modes of superplasticity of a particular material.

The greatest effect from the application of the method of superplastic shaping and diffusion welding can be obtained in the manufacture of complex multilayer structures of the type of sheathing with a different configuration of reinforcing elements. Such large-sized nodes can be obtained by the pressure of argon created between sheets, pre-diffusion welded. The superplastic material enters the cavities of the matrix, forming the required form of reinforcing corrugation. The method of forming with the expansion of the metal requires the use of a separating layer, which would not allow the flow of diffusion processes where it is not required. Formation with extension allows obtaining good results, since the gas pressure is distributed evenly and reliably by the adherence of the material to the matrix. Formation and welding occur at the superplastic state of the material; therefore, the work on the alignment of the connected surfaces for uniform fitting during welding is not required.

The technological process of manufacturing a large-sized knot of titanium alloys consists of a series of successive executed typical operations (Figure 3.14).

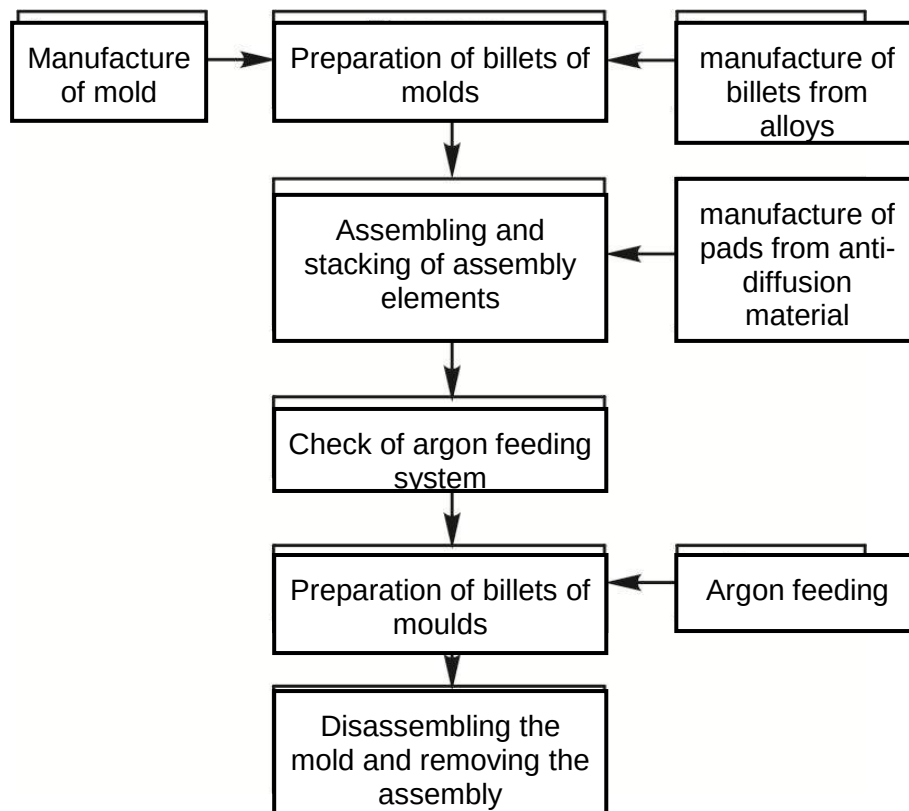


Figure 3.14 – Scheme of a typical technological process of manufacturing a large-sized titanium unit in a state of superplasticity

The result of the improvement of the method of superplastic formation and diffusion welding is the method of successive application of pressure and expansion (Figure 3.15).

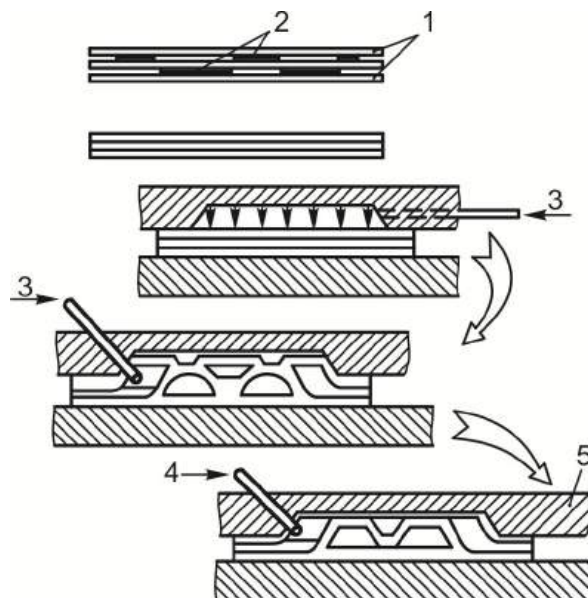


Figure 3.15 – The scheme of production of a titanium unit with internal cavities by the formation of successive use of pressure and expansion:

1 – sheet workpieces; 2 – anti-diffusion pads; 3, 4 – argon under pressure; 5 – mold

In this case, three sheet blanks 1 are used, between which separating anti-diffusion pads are installed in the required places. The process proceeds in a mold 5 and consists of one operation. At first, the pressure of argon is fed into the upper cavity of the mold to provide diffusion welding of the sheets. After the welding process is completed, the pressure from the cavity is leaked, the pressure of the argon is created between the welded sheets and the process of forming the node begins. In this case, the configuration of internal cavities is determined by the size of the sheet and the arrangement of anti-diffusion pads. Gas in the cavity zone is fed at a temperature of diffusion welding.

The results of the research of world firms in this direction are realized mainly in aircraft engineering. The technologies of manufacturing by the method of superplastic formation and diffusion welding of a number of structures made of titanium alloys are developed: two-layered panels in the form of a flat sheet reinforced by a hard sheet with rifts formed on it; three- and four-layer corrugated panels; three-layer heat-shielding panels with filler and other complex knots, which are often impossible to make in other known ways.

The technology of production of thin-walled ball-cylinders by the method of superplastic molding and diffusion welding is also of interest. (Figure 3.16).

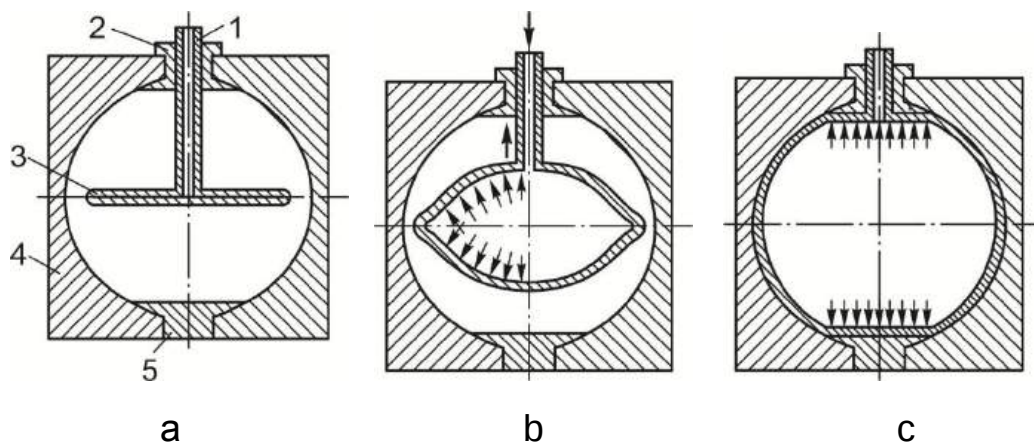


Figure 3.16 – Scheme for the production of ball-cylinders: a – installation of workpiece in the equipment; b – formation of the workpiece; c – diffusion welding of nozzle and flange; 1 – gas supply pipe; 2 – fitting; 3 – disk blank; 4 – equipment; 5 - flange

This technology involves the formation of a ball of hollow billets pre-made by diffusion welding along the perimeter and placed in the equipment, as well as the welding flange and fittings, located in the equipment, diffusion welding. According to this technology, ball cylinders are made of titanium alloy VT6ch. This increases the accuracy of the geometric sizes of cylinders and the strength of welded joints in comparison with the traditional technology of producing such cylinders by welding the melting of two stamped hemispheres.

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Навчальне видання

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