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DEVELOPMENT OF TECHNOLOGICAL SUPPORT OF QUALITATIVE THREADED JOINTS OF PARTS MADE OF ALUMINUM ALLOYS

Проведено аналітичне та експериментальне дослідження методу механічної обробки різьбових отворів при застосуванні деформуючого інструменту з урахуванням моделювання процесу формоутворення дюймових різьблень в глухих отворах деформуючим інструментом. Розроблено конструктивні і технологічні параметри деформуючого інструменту для глухих отворів під трубну різьбу в деталях з алюмінієвих сплавів з газоусадочной пористістю.

Ключові слова: *технологічний процес, різьбове з'єднання, алюмінієвий сплав, газоусадкова пористість, деформуючий інструмент.*

1. Introduction

Modern trends in the quality maintenance of machining of critical engineering products require the improvement of technological machining methods. In the paper, the housing parts of pneumatic equipment made of aluminum alloys that operate at a pressure of up to 1 MPa are considered. Parts are castings of medium complexity with overall dimensions from 50 to 160 mm, wall thickness from 2.5 to 8 mm and weight from several tens of grams to 1.5 kg. Die casting (DC), as a low-waste and high-performance process for obtaining precise castings of complex configuration with a high-quality surface, is widely used in machine building, automotive, tractor, instrument-making and many other industries. However, along with the advantages, DC has a one significant disadvantage: it is an increased gas and shrinkage porosity, and, as a consequence, low leakage of castings for products operating under pressure.

As connecting elements, the housing parts of pneumatic equipment have metric (up to M72), conical (up to K 1 1/2″) and pipe cylindrical (up to 2″) threads. The production of such threads by traditional methods using taps leads to the fact that during the thread formation, the pores are «opened». «Opened» pores can be isolated or form a system of through channels and cause leakage of the threaded joint. To ensure the tightness of threaded joints in cast parts with gas and shrinkage porosity, various sealants or the method of vacuum impregnation with compounds are used. However, the linear and volumetric thermal expansions that arise in the process of operation can reduce the operability of the products due to the loss of tightness of the detachable connections.

Obviously, when machining of a housing part, it is necessary to «close» these pores and isolate them from each other in the process of threads formation in the housing parts of the pneumatic equipment or before it. The method for preparation of the surface layer of blind holes in cast aluminum alloys can be based on the use of a special deforming tool. The development of technology using a deforming tool will make it possible to obtain a dense, porous surface layer and to ensure the tightness of threaded joints in the parts obtained by DC method. Thus, quality maintenance of manufacturing of blind threaded holes in housing parts made of aluminum alloys with gas and shrinkage porosity is actual. And tightness maintanence of threaded joints in products of pneumatic equipment operating under pressure up to 1 MPa is an urgent task.

2. The object of research and its technological audit

The object of research is the technological process of manufacturing of parts and assembly of hermetic threaded joints in products of pneumatic equipment made of materials with gas-shrinkage porosity operating at pressures up to 1 MPa.

From the algorithm in Fig. 1 it can be seen that after the preform 1 has undergone machining operation 2, according to the manufacturing process, using such machining methods as drilling, reaming, and boring operations. The part is sent to test operation 3 for surface quality testing by visual inspection of the hole, for the presence of pores and cavities that have arisen after mechanical removal of the metal layer. If the open pores or cavities have the dimensions of template 4 more than 1 mm but not more than 1.6 mm, they are sent for machining with methods of surface plastic deformation 6. That is, with the use of pre-deformation machining with a deforming tool and further knurling threads with deforming taps. If the dimensions of pores and cavities are less than 1 mm, then the part is machined according to the existing technological process to impregnate in vacuum with compounds 5. These methods are the most effective method for impregnating cracks and cavities up to 1 mm in size.

Afterwards, after machining with various methods, the parts are inspected on the stands for measuring leakage 7. The part is considered to be fit 8, provided that the leakage should not exceed 40 cm^3/min.

One of the most problematic places is the non-fulfillment of the leakage condition, the part is recognized as unusable and reject 9 is considered as irreparable.

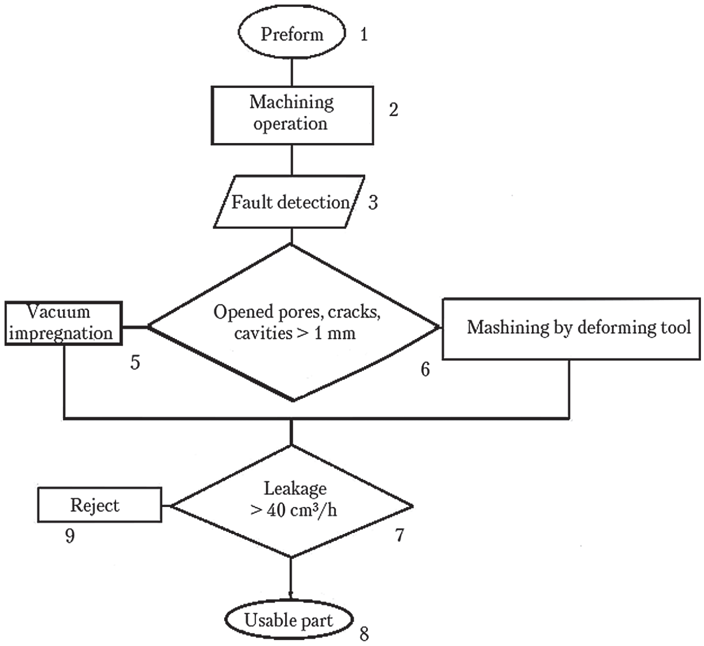

Fig. 1. Selection algorithm for machining technology

3. The aim and objectives of research

The aim of research is to improve of manufacturing quality of blind threaded holes in housing parts made of aluminum alloys produced by die casting (with gas and shrinkage porosity). In this case, a deforming tool is used to ensure the tightness of threaded joints in products of pneumatic equipment operating at pressures up to 1 MPa.

To achieve this aim, it is necessary to solve the following tasks:

1. To carry out a system analysis of the problem of obtaining hermetic detachable joints in the housing parts made of aluminum alloys produced by die casting.

2. To analyze the technological regularities of surface-plastic deformation of cast aluminum alloys, to develop a technique for experimental studies of the quality of processed surface, depending on the number of cycles and the angle of deformation.

3. To develop a mathematical model that allows to determine the geometric parameters of the deforming tool and its operating modes on the basis of the study of surface-plastic deformation process of AK12M2 alloy.

4. To develop a deforming tool that provides the required machining quality of surface threaded joints in the blind holes of parts made of AK12M2 alloy obtained by die casting on the basis of theoretical and experimental research.

5. To develop a technological process for the machining of blind threaded holes in housing parts made of aluminum alloys with gas and shrinkage porosity to ensure tightness of threaded joints in products of pneumatic equipment operating at pressures up to 1 MPa.

4. Research of existing solutions of the problem

In [1], the nature of the distribution of normal contact pressures along the contact surface of the tool with the preform is determined, depending on the hardening gradient of the surface layer. It is also shown that large shear deformations are necessary to form a dense surface layer, under which the pores are «healed».

In [2], the developed theoretical model is shown, which allows to calculate the stress-strain state parameters of thick-walled preforms processed by deforming pulling. However, in this research, machining of blind threaded holes is not examined due to the impossibility of applying the doving for this operation.

In [3], one of the ways of solving the manufacturing of a composite deforming element consisting of a steel bearing ring and an outer carbide part is presented. However, this method can not be used to process blind holes.

The authors of [4] developed a deforming tool that allows machining of blind holes made of aluminum alloy parts with gas and shrinkage porosity. But at the same time, technological support for the application of this tool has not been developed.

The author [5] investigated the theoretical dependences of leakage of hermetically sealed metal compounds on the machining conditions of contacting surfaces of parts. However, the author did not take into account the influence of pressures up to 1 MPa, as well as the effect of gas and shrinkage porosity and the appearance of rejects due to machining.

In [6], structural elements of mechanical seals, manufacturing technology, installation requirements are considered, but the effects of interstitial leakage due to «opening» of pores by machining aren't take into account.

The new sealing material developed in [7] operates at high temperatures, but it does not take into account the influence of vibrations arising during the operation of the product, as well as the effect of negative temperatures.

In [8], it is shown how to determine the tightening torque for pre-tensioning of the target during the pre-tightening of the threaded flange in parts working under pressure. However, the effect of the thread profile surface on the tightness is not shown.

In [9], threaded joint for oil pipes and casing and its failure due to a deterioration in the sealing performance and strength of the joint are considered. However, the effect of removing the casting crust and the effect of «opening» of pores is not shown.

New, non-invasive ultrasonic method that provides an immediate means of mapping the penetration of liquids into threaded systems, in [10] does not consider methods of cavity sealing resulting from machining.

Small-sized M3-M6 taps and machining of parts made of aluminum alloys with their help are considered in [11]. But this work does not take into account the effect of gas and shrinkage porosity that occurs during casting, since only rolling is considered, which is not relevant from the point of view of producing pneumatic equipment. Also the value of the sizes of threaded holes used in pneumatic distribution devices is not taken into account.

From the analysis of published data it is established that the problem of processing of blind threaded holes in parts obtained by casting made of aluminum alloys by surface plastic deformation methods is poorly understood. Also, there are no studies of the technological properties of an aluminum alloy with a gas and shrinkage porosity obtained by die casting and the design procedure for technological processing operations as a factor of productivity and machining quality of detachable joints.

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5. Methods of research

On the basis of system analysis, the problems of obtaining hermetic detachable joints in housing parts made of aluminum alloys obtained by die casting are investigated. Theoretical studies are based on the main provisions of engineering technology and the theory of cutting. Based on the basic principles of surface-plastic deformation theory, a technique for experimental studies of processing surface quality is developed, depending on the number of cycles and the angle of deformation. Analysis of macrostructural images of surfaces obtained before and after deformation is performed using the program «FemtoScan Online» (Russia).

To study the regularities of the surface-plastic deformation (SPD) mechanics, the following technique is proposed: SPD is carried out along the outer surface of a cylindrical cast preform obtained by die casting made of AK12M2 alloy (Fig. 2).

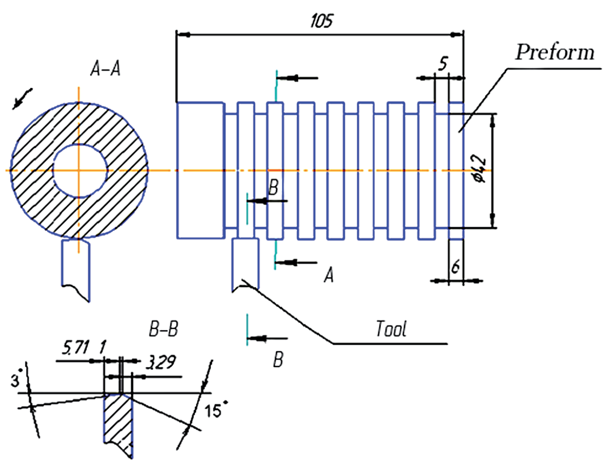

Fig. 2. Technique for studying the regularities of surface plastic deformation mechanics of cast aluminum alloys

To ensure the porosity is the same as for the machined products, the models (preforms) are cast under the same technological conditions, but with different densities. The density is varied by applying various pressing forces in casting to ensure that the model is adequate to the production products. The density parameters are determined from known dependences with an accuracy of ± 0.001 g/cm^3.

Rolling is carried out with the help of deforming tools. The deforming tools are made by re-grinding of the straight cutters made of P6M5K5 high-speed steel with an accuracy of $\pm 0°10'$.

6. Research results

Structural analysis shows that the surfaces are formed similarly when smoothing, but the crust is previously removed by grinding. To form a dense surface layer, large shear deformations are necessary, under which the pores «heal». Multi-cycle (stepwise) SPD with a number of cycles of 8–15 are used in the studies. Projections (grooves) for each of the projections are cut for this purpose. Each of the models are used its own number of cycles, thus presenting an opportunity to analyze the influence of the number of cycles on the surface quality. The cycle in this case is the contact interaction of the model with the deforming tool for one spindle revolution. The number of spindle revolutions of 25 rev/min and the cross-feed rate of 0.05 mm/rev are adopted according to the recommendations on the deformation rate.

During the experiment, the following data are obtained (Fig. 3) for a preform with a density of $\rho = 2.735$ g/cm^3 and a tool with a deformation angle of 4 degrees at a strain rate of $\xi = 3.77$ m/min, Sc = 0.05 mm/rev. Macrophotographs (Fig. 3, *a*, *b*) and topography (Fig. 3, *c*, *d*) show that the pore closing after 8 cycles is not complete and as a result there is no shear deformation. Based on these data, it can be seen that these regimes are not optimal. Therefore, the number of cycles must be increased.

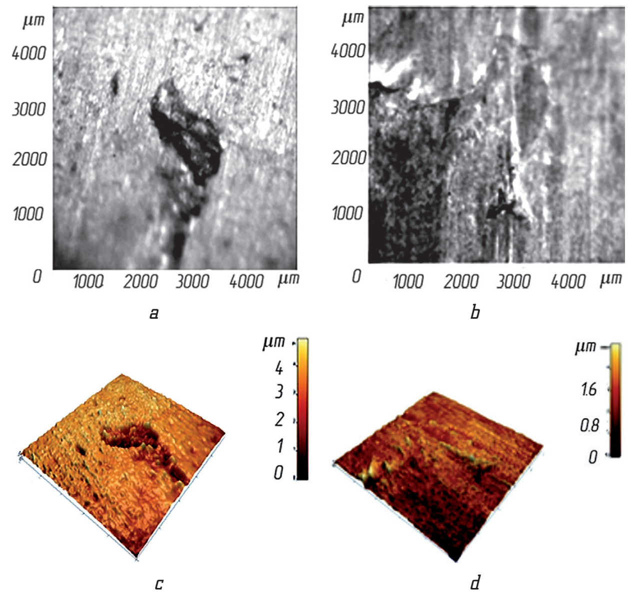

Fig. 3. Preform № 1 before surface plastic deformation with a density of $\rho = 2{,}735$ g/cm^3 and tool with a deformation angle of 4 degrees at a strain rate of $\xi = 3.77$ m/min, Sc = 0.05 mm/rev: *a* – macrophotography of the «opened» pore; *b* – macrophotography of the «closed» pore after deformation; *c* – topography of the «opened» pore processed in the «FemtoScan Online» program (Russia); *d* – topography of the «opened» pore processed in the program «FemtoScan Online» (Russia)

Further, for the same preform, after conducting a series of comparisons of the pores before and after deformation it can be concluded that the optimal modes are the deformation angle of 4 degrees at a strain rate of $\xi = 3.77$ and 13 loading cycles (Fig. 4).

To identify the effect of pore «closing» and the most high-quality surface, visual methods of observation using a ПМТ-3 microhardnesser (Russia) are used. The pores and macrocracks on the preform surface are photographed before and after SPD (Fig. 3, 4).

Based on these data, we can state that at SPD of AK12M2 aluminum alloy, it is possible to obtain a qualitative surface.

Comparing the values, we came to the fact that the deformation rate in the case of cold plastic deformation influences not so much on the surface quality of AK12M2, as the number of cycles and the angle of deformation.

Taking into account the above data and the results presented in [12–14], a deforming tool is created (Fig. 5).

The created tool consists of a shank (∅ 8 mm) and a deforming part (L), which in turn has four deforming blades. The angle of the blades of the deforming parts is 4 degrees. The deforming part has a sampling (d_s), deforming (d_d), calibrating ($d_{d,\ 0.5}$) and reversed cone for the return of the tool from the part.

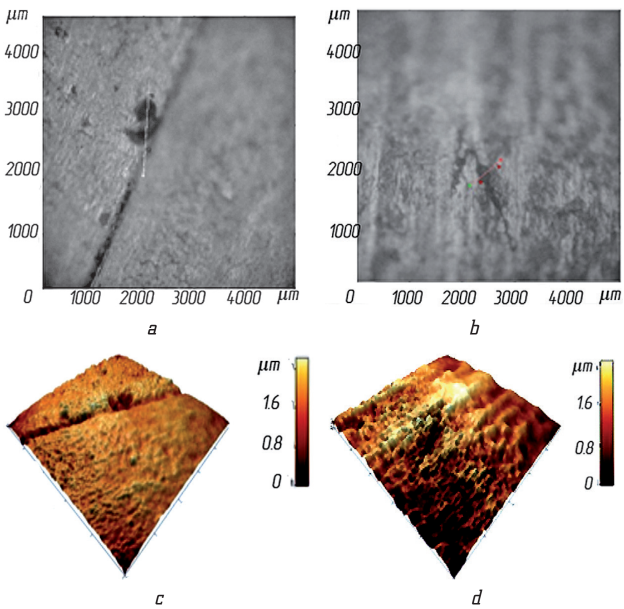

Fig. 4. Preform № 1 after surface plastic deformation with a density of $\rho=2.735$ g/cm^3 and tool with a deformation angle of 4 degrees at a strain rate of $\xi=3.77$ m/min, Sc=0.05 mm/rev: *a* – macrophotography of the «opened» pore; *b* – macrophotography of the «closed» pore after deformation; *c* – topography of the «opened» pore processed in the «FemtoScan Online» program (Russia); *d* – topography of the «opened» pore processed in the program «FemtoScan Online» (Russia)

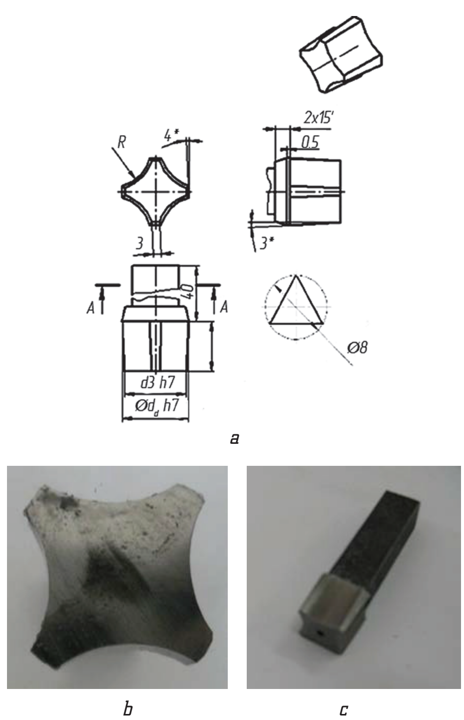

Fig. 5. Deforming tool: *a* – the structural dimensions of the deforming tool; *b* – manufactured deforming tool from the end; *c* – manufactured deforming tool

Case machining of ПКР-25 valve produced at JSC «Pnevmatika» (Simferopol, Crimea) with the use of a new deforming tool allows to obtain hermetic detachable joints in the parts made of aluminum alloys.

The results of the conducted studies make it possible to give practical recommendations on the technological provision of tightness of threaded joints of parts based on surface-plastic deformation, which are introduced at enterprises.

The introduction of a new (prospective) technological process for machining of a threaded hole in the case of a pneumatic distribution valve allows to increase productivity, instead of impregnating in a vacuum and also to reduce the roughness of machined surface of joint surfaces, and also to increase further operational reliability.

7. SWOT analysis of research results

Strengths. A technological operation with the use of a deforming tool as part of a new technological process for the machining of blind threaded holes in the housing parts made of aluminum alloys with gas and shrinkage porosity is developed. In the basic technological process, after machining, the parts are rejected in case of pore opening larger than 1 mm (the rest are subjected to subsequent compound impregnation). And in the new technological process, open pores up to 1.6 mm in size are eliminated by machining with a deforming tool, reducing the share of rejects to 5 %.

Practical recommendations and results of theoretical and experimental studies on improving the machining quality of blind threaded holes by deforming tools have been developed. Developments have been implemented at JSC «Pnevmatika» (Simferopol, Crimea) in the technological processes of processing of pneumatic equipment, working under pressure up to 1 MPa. This allows to reduce the technological cost and get an economic effect in the amount of 18207.44 UAH due to the reduction of the labor intensity of machining and the cost of process fluids during vacuum processing.

Weaknesses. The weaknesses of this research are related to the fact that a new processing step is introduced in the existing machining of ПКР25 part, thereby increasing the fraction of the main machining time of the part.

Opportunities. Additional opportunities to achieve the aim of research are the fact that improving the manufacturing quality of blind threaded holes in the housing parts made of aluminum alloys obtained by die casting (with gas and shrinkage). To ensure the tightness of their threaded joints in products of pneumatic equipment operating at pressures of up to 1 MPa in production, high-cost impregnation of parts with compounds in vacuum is used, which significantly affects the cost of production.

Threats. Threats in implementing the research results are related to the development of new technological documentation, as well as the production of a new deforming tool for different sizes of threaded holes.

Thus, SWOT analysis of research results allows to identify the main directions for the successful achievement of the aim of research. Among them:

– to develop a technological process for machining of blind threaded holes in the housing parts made of aluminum alloys with gas and shrinkage porosity;
– to ensure the tightness of threaded joints in products of pneumatic equipment operating under pressure up to 1 MPa, using a deforming tool for different thread sizes;
– to develop a technological process for the machining of blind threaded holes in the housing parts made of aluminum alloys, taking into account the absence of further impregnation of the parts in vacuum.

8. Conclusions

1. On the basis of a system analysis of quality maintenance problem of manufacturing of hermetic detachable joints in the housing parts made of aluminum alloys produced by die casting (with gas and shrinkage), it is established that when obtaining a thread using traditional methods of cutting taps, pores are «opened». Pores can form a system of through channels and cause revenue (up to 20 % of products) that can't be eliminated even by subsequent methods of compound impregnation.

2. Conditions of quality maintenance of machined surface depending on quantity of cycles and an angle of deformation are defined on the basis of research of technological features of AK12M2 aluminum alloy and process of its surface-plastic deformation. This allows to develop a mathematical model for determining the geometric parameters of the deforming tool and its operating modes. Modes: number of loading cycles – 12–13, deformation angle – 4 degrees, deformation rate – $\zeta=3.77$ m/min with cross-feed rate – $S=0.05$ mm/rev. Modes provide the required quality of surface machining for thread in the blind holes of parts made of AK12M2 alloy.

3. Analysis of the results of machining with a deforming tool shows that the reject in the form of an incomplete thread profile arises as a result of inaccurate calculation of the average diameter of the hole for rolling. The resulting model of an inch thread profile for calculating the diameter under rolling processing makes it possible to determine the average diameter of the rolling hole for the pipe threads of the first (preferred) row. Calculated constructive and technological parameters of surface-plastic deformation processing of AK12M2 alloy makes it possible to create a new deforming tool for blind holes [4].

4. On the basis of theoretical and experimental studies, a deforming tool is developed that provides the required surface quality of threaded joints in the blind holes of AK12M2 alloy parts obtained by die casting.

5. A technological operation with the use of a deforming tool as part of a new technological process for machining of blind threaded holes in the housing parts made of aluminum alloys with gas and shrinkage porosity is developed. In the new technological process, open pores up to 1.6 mm in size are eliminated by machining with a deforming tool, reducing the share of rejects to 5 %.

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РАЗРАБОТКА ТЕХНОЛОГИЧЕСКОГО ОБЕСПЕЧЕНИЯ КАЧЕСТВЕННЫХ РЕЗЬБОВЫХ СОЕДИНЕНИЙ ДЕТАЛЕЙ ИЗ АЛЮМИНИЕВЫХ СПЛАВОВ

Проведено аналитическое и экспериментальное исследование метода механической обработки резьбовых отверстий при применении деформирующего инструмента с учетом моделирования процесса формообразования дюймовых резьб в глухих отверстиях деформирующим инструментом. Разработаны конструктивные и технологические параметры деформирующего инструмента для глухих отверстий под трубную резьбу в деталях из алюминиевых сплавов с газоусадочной пористостью.

Ключевые слова: технологический процесс, резьбовое соединение, алюминиевый сплав, газоусадочная пористость, деформирующий инструмент.

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