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VALIDITY OF WIDE USE OF POLYMER COMPOSITE MATERIALS

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Abstract
This paper examines the widespread application of Polymer Composite Materials (PCMs) across diverse industries, emphasizing their pivotal role in enhancing technological development. With superior properties such as strength, ductility, and corrosion resistance, PCMs significantly contribute to weight reduction in aerospace components, as evidenced by their 35% incorporation in Boeing 737 and Airbus A320 aircraft. The study delves into the challenges encountered during PCM machining, particularly in cutting mechanisms and material defects, highlighting the need for comprehensive research in this domain. Despite these challenges, the economic advantages and technological progress facilitated by PCMs remain undeniable. The paper underscores the critical balance between harnessing the benefits of PCMs and addressing machining complexities to ensure their continued validity in a wide range of applications.
Keywords: Polymer Composite Materials (PCMs), Aerospace industry, Fiberglass materials, Strength-to-weight ratio, Aircraft components, Gas turbine engines, Space technologies, Thermal resistance, Machining challenges, Cutting mechanism.

Introduction

The level of technological development of countries is determined by many aspects. Polymer composite materials (PCM) are used in aircraft engineering, shipbuilding, rocket and space industry, automobile industry, high-tech industries in the production of sports equipment, energy, electronics, medicine and other industries. PCMs have superior strength, ductility, hardness, corrosion resistance and other properties than some steel materials.

The strength properties and the inherent low gravity of composites compared to metals allow to reduce the mass of the finished part without losing its rigidity and reliability. The share of aerospace materials in the total volume of production is about 1% of composites (Figure 1), but their value is invaluable because it is these knowledge-based industries that provide a catalyst for progress in other areas and the emergence of new technologies [1].

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Literature review

In the aircraft industry, PCM components with high strength and low specific gravity are attractive structural materials.

The use of polymer composites and their advanced technologies reduces the weight of the aircraft, increases its reliability and reduces economic costs.

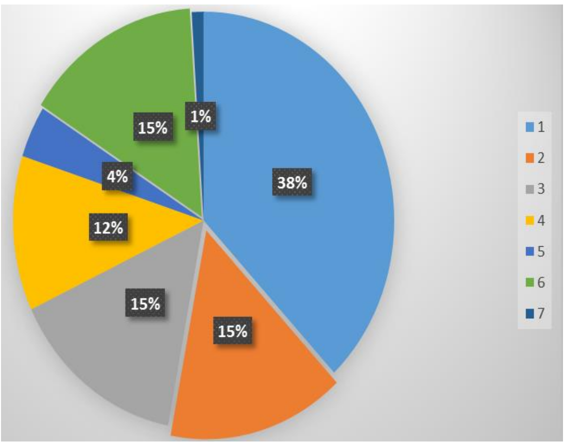

Figure 1. Fields of application of polymer composite materials according to the information of the Institute of Composites [1].

1- in aerospace industry (1%), 2- in industry (15%), 3- in shipbuilding (15%), 4- in electrical engineering and electronics (12%), 5- in transport (38%), 6- in construction (15%), 7th in household appliances (4%)

In Boeing 737 and Airbus A320, 35% of aircraft parts are made of polymer composites. (Figure 2) [2].

Figure 2. MS-21 Aircraft Component Unit [52]

In the design of gas turbine engines, successive replacement of metal body parts with composite materials 90A2, PS-12, and D30KU-154 reduced the weight of the product by 20-30% and increased performance [1].

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PKMs are also actively used in space technologies. For example, the doors of the instrument compartment of the space shuttle's orbital stage are made of polymer composite material.
Composites are also effectively used to solve thermal problems. It is difficult to protect and reduce the mass of the orbital during aerodynamic heating (Fig. 3). The most responsible parts are the nose cone and the leading edges of the wing, which are made of heat-resistant PKM [4].

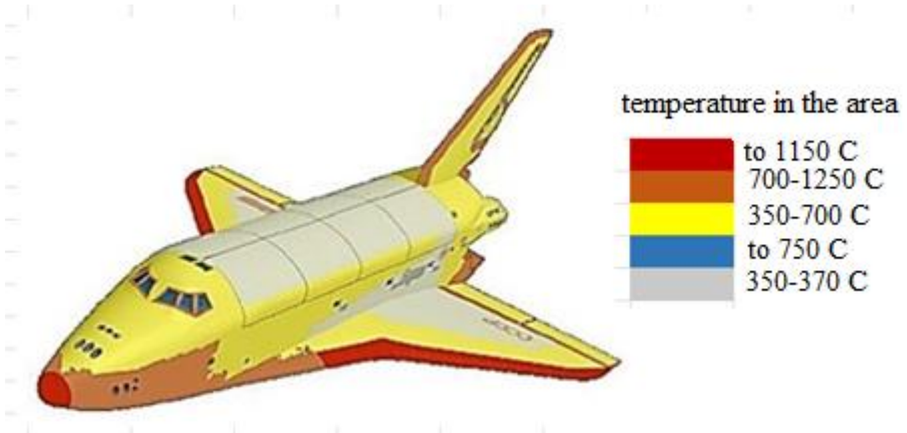

Figure 3. Heat-resistant PKM parts of the orbiter

One of the most common groups of composite materials in the aviation and rocket space industry is fibreglass materials based on thermosetting binders. Fiberglass materials are the most difficult to process PCM. PKM is divided into group VI by processing (where group I is the easiest to process PKM, and group VI is the most difficult to process PKM).
Since their introduction, the use of glass-coated PCMs in the world industry has been increasing (Figure 4), and the trend will continue for the next decade [5].

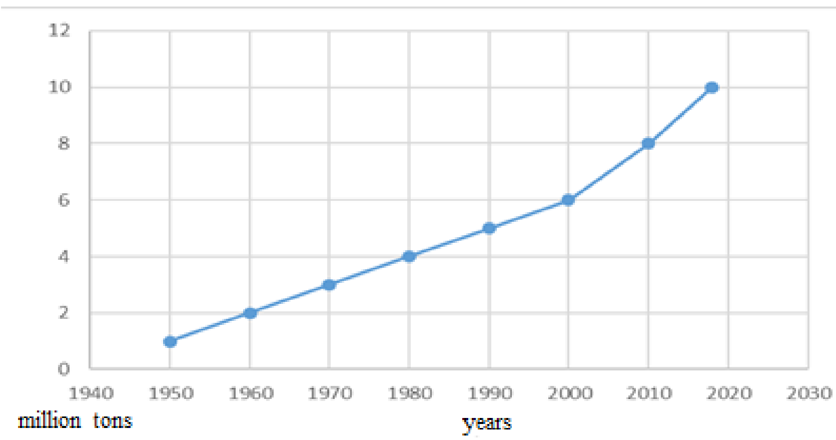

Figure 4. Requirements for the PKM year

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The main components of PKM are fibreglass reinforcing materials and synthetic binders. Thin and high-strength glass fibres provide strength and rigidity. The connecting material provides strength and helps to use the mechanical properties effectively [6].

The biggest problem is that when machining the mounting holes, cuttings are removed from the drilling area and the cuttings adhere to the drill, causing defects in the holes.

Studies conducted by several authors revealed a significant difference between the cutting mechanism of the cutting tool. PCM and metal alloys. To date, the nature of the process of cutting metal alloys has been very well studied. During processing, the formation of chips occurs as a development of the plastic deformation process on the front surface of the cutting tool.

Due to the lack of a clear methodology, the mechanism of crumb formation does not depend on the direction of cutting. The height of the microcracks inside the surface treated with constant technological parameters is constant and does not change after the end of the cutting process.

The following are the main factors that determine the low performance of metal alloys:

1. Low thermal conductivity of metal alloys, which is insufficient removal of heat from the cutting zone and, as a result, overheating of the tool.

2. Heating the cutting zone, the interaction of the metal alloy with oxygen, nitrogen and hydrogen in the air promotes a chemical reaction, and solid compounds are formed. The penetration of gases present in the air leads to the stabilization of the phase and deterioration of its mechanical properties. Both factors lead to the formation of surface mechanical properties of the metal alloy, comparable to the properties of the tool material, which leads to progressive wear of the tool.

3. Metal alloys have a tendency to stick and also undergo chemical reactions with the processing agent. It is common to describe these phenomena as "sticking" and "humiliation". The indicated negative events are mainly explained by the high temperature in the cutting zone. This leads to a further worsening of the heat release from the exit zone and, as a result, a further increase in temperature. The process of cutting PCM is significantly different from the process of cutting metals and metal alloys. The main reason for the difference is the apparent anisotropy of PKM properties [7]. The anisotropy of PCM properties affects the process of slag formation. Depending on the current direction of the filler fibres relative to the velocity vector of the tooltip, four main PKM cutting mechanisms are distinguished: microlamination (th = 00), cutting of fibres (th = 450), grinding of fibres (th = 900), tearing of fibres (th = - 450).

Each cutting mechanism is characterized by a specific micro geometry of the processed surface. When drilling PCM holes, the cutting angle of the fibre is constantly changing from 900 to - 900, so the hole contains defects such as "tears" and uncut fibres at the same time. In addition, after the end of the cutting process, uncut fibres can recover and change the micro geometry of the surface and therefore the dimensions of the hole to be processed.

Drilling holes in PCM is accompanied by many technological problems: the formation of defects that are characteristic only for the processing of composites, the impossibility of using

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cutting fluids, the difficulty of obtaining high-quality holes due to the reduction of holes, and the bending of the cutting tool. Typical defects of drill holes in composites are pitting, cracking, thermal damage and fusion of the polymer matrix, and microcircuits between the fibres and the binder.

Many researchers emphasize the effect of cutting conditions on the surface quality and accuracy of hole processing. In addition, to reduce the defects of PKM, it is necessary to set a high cutting speed and low suction, but when PKM is processed together with a metal alloy, this requirement is contradictory due to the significant heat generation.

Processing of holes in mixed packages is usually carried out at the last stages of product production, including the assembly process. The high cost of eliminating defects at these stages can lead to incorrect estimates of machining rates and the use of a large number of passes to reduce defects. These actions help to significantly increase the cost of assembly work and the product as a whole. Only the scientific determination of cutting conditions and the minimization of the number of passes reduce the cost of processing holes in mixed packages.

Results

Observing and researching progressive methods of mechanical processing of drills on non-technological surfaces of composite parts used today in mechanical engineering allows us to choose the necessary direction, improve it and thus achieve a more effective result.

Creating and designing a special structure of drills that ensures high dynamic resistance and stability in a given direction, reduces the condition of chip separation during composite detail processing, especially when the drill penetrates the surface of the detail.

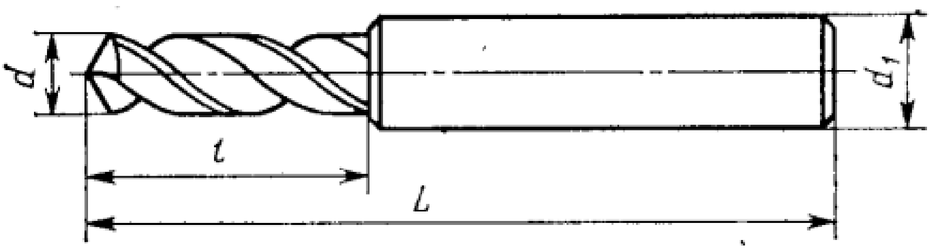

Figure 5. Hard alloy spiral drill.

In the process of drilling open holes or bevelled surfaces of the workpiece, a drill with a tip enlarged at an angle of 140° should be used, and it should be remembered that the double-drilling method is not used.

Creation and implementation of constructions that generate "centripetal" forces that reduce cutting errors when processing non-technological surfaces of parts, as well as ensure the reliability of the tool's operation at the stage of exit from the non-technological surface of the cutting tool.

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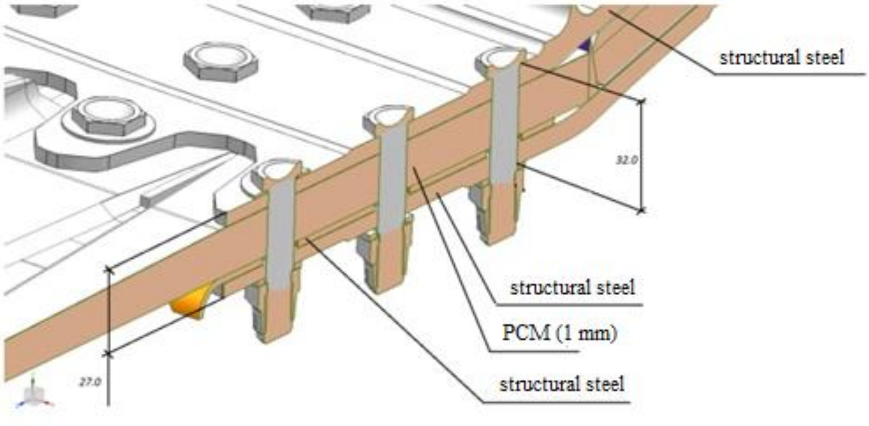

Figure 6. Package made of metal and composite materials

In the mechanical processing of details, it is necessary to pay great attention not only to increase the productivity but also to increase the quality indicators. In the past, much research has been devoted to investigating the cause of geometrical errors in holes made by spiral drilling. As a result, asymmetry in the cutting part of the drill (ie, the relative interference of the main cutting teeth) has been shown to have a large effect on the size and out-of-roundness of the hole. It was also noted that the displacement of the hole from the axis is due to the displacement of the drill due to a certain error of the machine in the first minutes of processing.

The fact that the inner walls of the hole drilled with Parma are parallel creates the basis for the quality of further processing, deburring and grooving operations. It is important to be straight and level, especially for deep holes.

The geometric errors of the hole are different, its sides differ in shape, and roundness errors differ in depth.

In the static state, the actual diameter of the hole is determined by the following factors:

a) Parma's own eccentricity;

b) Eccentricity of the passing spindle and bushing;

c) Roughness of the treated surface.

It was found that the eccentricity of the spindle and bushing of the drill can be compensated in such a way that the system works smoothly without causing the drill to be asymmetrically bent. In this case, you can get accurate information about the size of the hole.

It was also determined that the size of the hole becomes larger than the nominal size in the following cases:

a) When the beam deviates from its axis due to insufficient stiffness;

b) When the workpiece being processed moves to one side due to insufficient locking;

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Therefore, the accuracy of the hole drilled with a drill depends on the impact of the drill bushing-spindle system, the conditions of the workpiece being fixed, and how accurately the drill is drilled.

Based on the above, it is possible to come to the following conclusion:

a) Ensuring the required accuracy of mechanical processing of holes of non-technological details in mechanical engineering means ensuring the efficiency and quality of mechanical processing given to this hole.

b) Increasing the accuracy of mechanical processing of the hole on the non-technological surfaces of the parts.

The use of additional energy sources aimed at breaking the surface layer of the part being processed is the most promising research carried out in the fall. In this aspect, the simple method of drilling a hole is seen in the method of applying additional mechanical energy by means of centring drills, as a result of which the main cutting tool tip is easier to cut into the part. The authors of this project are offered a new method of mechanical processing of holes with a drill**.**

The authors of this project propose a special design of the conductor bushing for the mechanical processing of holes of non-technological machine parts with a drill. In this case, the end of the conductor bushing has the shape of a surface where the hole is fixed.

The surface of the polymer workpiece, which is machined with Parma, must be plastered to the conductor bushing. Conductor bushing has the ability to slide along the drill axis so that cuttings do not get stuck between the cutting face and the conductor bushing.

This possibility is provided by two double-spring guides 3 and 4.

The characteristics of hole processing in mixed packages impose restrictions on the type of tools used. This is mainly due to the large and complex shape of processed products (aggregate units). Thus, the use of stationary equipment, despite its wide range of possibilities, is in many cases impossible or economically unfeasible in relation to the processing of holes in packaging. Given the serialization of production typical of large manufacturers in the aviation industry, such as Boeing and Airbus, robotic systems can be used for these operations. A promising work used in the process of assembly of caps with PKM contours is the robotic system of Elektroimpact Inc. [8-14].

The basis of this system is a KUKA manipulator with seven degrees of movement. An adaptive drilling head with an automatic suction and dust absorption system is used as the working element of the manipulator.

A manipulator placed along the assembly unit to be processed moves along the rail using the system-controlled digital control. A multifunctional device containing four main modules is used as a working element of the system: - a spindle module with the ability to suck the processing device in the axial direction;

– a module for fixing the device on the workpiece (the mechanism for processing the workpiece of the clamp);

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- module for accurate control of the machined hole using a pneumatic stylus gauge;
- hole management module through a video surveillance system with an image recognition system in the form of a special program.
- Since each material requires an individual processing mode when processing packages based on PCM and metal alloy, the spindle unit operates in two modes: - high speed and low speed (for processing holes in the composite part of the package); - high torque and low speed (for processing part of the metal alloy package).

The design of the module is made in such a way that the control process of the machined hole can be combined with the subsequent processing. The module for fixing the device to the machined surface is necessary to base the structure in relation to the machined position [15-19]. The base is the surface of the workpiece. Compression is performed by a separate driver that is part of the clamp module. The task of the robot is to place the device in the plane of the part. Such a fastening scheme provides a solution to two main problems:

- directing the axis of the tool to the normal machined surface, regardless of the spatial orientation of the surface of the part in the machining zone;
- increasing the stiffness of the mechanical system due to the power circuit of the console structure of the manipulator in the part.

This design feature is especially important when processing a part of a package made of metal alloy, where the rigidity of the mechanical system is one of the main conditions that ensure the regulated resistance of the processing tool, the stability of the cutting process and the accuracy of the processed hole.
The precision control module of the machined hole is based on the use of a specially calibrated probe. The deviation from the nominal diameter of the hole is determined by the air pressure in the space between the surface of the probe and the wall of the hole. The size of the diameter control device is 0.04 mm. This installation allows you to process holes in one pass, a special drill is used as a cutting tool. Ensuring the desired quality of the machined hole is achieved due to the special design of the cutting tool and careful selection of cutting conditions [18-20].
In a mixed package, the processing of holes is accompanied by the appearance of defects in the metal and composite parts of the package. The quality parameters of holes in metal elements are well known, and errors in diameter, hole shape and surface microgeometry parameters are usually detected. Holes in PKM are characterized by additional defect types.
Diametrical errors (size and shape errors) of the hole in PKM are most clearly manifested at the tool entrance. Tool exit diameter errors are usually less. The cause of this type of defect is usually the removal of additional material from the walls of the PKM opening with metal alloy scrapers at the stage of drilling the metal part of the package. During drilling, metal shavings move from bottom to top along the side channel of the drill, having sharp edges and high temperatures. Since the KM polymer matrix has a low hardness, the movement of the cuttings leads to an undesirable "cutting" of the material from the wall of the hole. Often, this leads to

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errors in the form of holes in the package. Defects related to the texture of PCM occur due to the anisotropic structure of the material due to the mismatch of the crumb.
Defects in the exit of the tool from the hole are the result of the development of the PCM destruction process in the area of the drill tip when exiting the PKM. There are two main types of such defects: uncut fibres and threading. The first is the remnants of the PKM filler fibre left on the edge of the hole on the outlet side of the tool. Since their formation is oriented in relation to the vector of the exit speed of the filler fibres in this area, the moving edge does not cut them but grinds them. As a result, the scraps are bent to the edge of the hole in the suction direction and partially recover their original shape after the cutting process is completed. The second type of defect at the output of the tool is associated with "delamination" of the material due to insufficient interlayer adhesion of the filler layers. Certain studies on the search for models of the process of drilling holes in mixed packages are aimed at determining the effect of the technological parameters (factors) of the cutting process on the parameters of the surface quality and the accuracy of the holes. For this, authors use different approaches. Artificial neural networks are widely used to study the dependence of hole quality parameters on PCM on cutting conditions and geometric parameters of the cutting tool.

Conclusions

The analysis of the world experience of processing holes in mixed packages allowed us to draw the following conclusions:

1. The completely different requirements for the cutting process of PCM and metal alloys cause several problems: high bending of the tool, high temperature in the cutting zone, the formation of hole defects in PCM
2. The best solution to improve the accuracy and quality of the processing of the holes in the packages is to combine cutting methods that take into account the processing characteristics of PCM and metal alloys with a scientifically based mark.
3. The most common and promising equipment for processing holes in packages containing PCM and metal alloys is automatic drilling machines.
4. It is not recommended to use cooling water when processing packages containing RMB. A compromise solution found is to use a minimum number of SOTs in the fog view.
5. Techniques related to the construction of neural networks, methods of finite element modelling and mathematical statistics are the main approaches to the study of the parameters of the hole processing process.
6. In PCM and metal alloy packages, there are no correct models describing the effect of cutting conditions on surface quality and hole accuracy.
7. There are no methods for calculating the effect of temperature factors of the cutting process on the accuracy of holes in packages containing PCM and metal alloys.
8. Tools (drills) for processing mixed packages are mainly produced by foreign companies, have a very high price and do not guarantee the required accuracy of the holes.

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