Assessment of climatic processability of polymeric materials used in the repair of machines in the Arctic

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Abstract. The results of studies of the properties of polymer composite materials that can be used in the repair of machines under conditions of constant, prolonged exposure to negative temperatures (Arctic conditions) are presented. The main indicators of technological effectiveness in the repair of machines under conditions of constant exposure to negative temperatures using polymer composite materials are evaluated. The qualitative and quantitative indicators of the technological effectiveness of polymer composite materials used in the repair of machines are also evaluated. To assess the technological effectiveness of repair materials, a qualitative criteria is suggested - an integral coefficient that takes into account the errors in the performance of each technological operation.

1. Introduction

The quality of machines depends on the quality of manufacture, control, diagnostics, operation and repair. At each of these stages of the machine's life cycle, quality indicators are added that are related to the materials used, equipment, tools, equipment during manufacture and assembly. There are many standardized methods for assessing the quality of machine parts of metals and alloys [1-3], whereas when using non-metallic materials, quality assessment is carried out for the material [4-6], less often for a part or product [7-8].

Generally, consideration of quality assurance issues begins with an analysis of external and internal factors that have the most significant impact [9]. The authors of [10] indicate that «The environment creates a significant impact on the reliability of machinery and equipment operating in different climatic conditions». However, in the technical literature, much attention is paid mainly to the issues of working with lubricants. Their quality directly affects the reliability of moving parts and the effects of negative temperatures are studied to a much lesser extent.

The purpose of this work is the analysis of indicators of manufacturability in working repair conditions of machines using polymer composite materials (PCM) with a constant, long-term exposure to negative temperatures (in the Arctic).

Technological effectiveness is one of the most important indicators of the quality of various machines and mechanisms [1, 11] and is regulated by GOST 14.205-83 «Technological effectiveness of product design. Terms and definitions». In accordance with this document, the technological effectiveness is understood as «a set of design properties of a product, determining its ability to achieve optimal costs in production, maintenance and repair for given indicators of quality, output and working conditions».
2. Results and discussion

The most significant difference in requirements for the manufacturability of parts made of metals and PCM is at the stage of repair and disposal (table 1). Manufacturability in the recycling of metal parts is more declared, while for PCM many new classes of biodegradable materials and new technologies for their recycling have been created. To ensure the manufacturability from the standpoint of repair, metal parts can be complicated, which leads to a decrease in their technological effectiveness. An example of things that can complicate the process include: the manufacture additional channels for lubricant supply, replaceable sleeves, etc.

Table 1. Evaluation of factors of technological heredity in the manufacture and operation of products produced from metals and polymer composite materials

| Characteristics | Metals and alloys | Material | Polymer composite materials |
|-----------------|-------------------|----------|-----------------------------|
| The purpose of determining technological heredity | To monitor the condition of the part in the process of its manufacture and operation. To determine the conditions under which errors occur that exceed permissible limits. | Inherited information | Properties of materials. Properties of surface layers. |
| Main inherited value | Inherited information | Properties of materials | Properties of materials |
| Method of transmitting inherited information | Sequentially from one process operation to another. | There are no uniform patterns | |
| Key performance indicators | Reliability indicators (durability, maintainability). Wear resistance. Contact stiffness. Corrosion resistance. | Deformation-strength, electro-physical, optical and other special properties. | |
| Factors that have the greatest impact on inherited information | Characteristics of the surface layer. Modes of blade processing. | Strength characteristics of materials. Material structure at various scale levels. | |
| Technological inheritance of structural forms of parts | Takes place in every process operation. | Is not present. | |
| The manifestation of technological heredity | At the stage of production, storage and operation. | | |
| Areas where the influence of technological heredity factors is most significant | Precision engineering. | Manufacture of all products. | |

To ensure technological effectiveness at the manufacturing stage, a special set of measures related to the development of products for manufacturability is provided. As a rule, at this stage, the issues of introducing advanced technological solutions are solved, the scientific substantiation of safety margins is fulfilled, etc. However, in the technical literature there is no information on the development of a product for manufacturability from the standpoint of repair under the influence of negative temperatures (in Arctic conditions).

In this work, to identify these factors for the repair of machines under conditions of prolonged exposure to negative temperatures, it is proposed to use the concept of climate adaptability. Repair technologies and materials will meet the requirements of climate adaptability in the event that they
provide the specified quality of repair with minimal changes to the basic technologies that do not entail a significant increase in the costs of actual and materialized labor.

Thus, the requirement of climatic technological effectiveness will be fulfilled only if adequate replacements of materials and technological operations are found, the use of which will allow not only to retain standard repair technologies, but also quality and repair time.

Let us consider the main indicators of climatic manufacturability by quantitative and qualitative criteria, as applied to the repair of exhaust systems of road machines using PCM.

In table 2 displayed is a list of the main technological operations in the repair of machines using polymer composite materials [11]. All technological operations are standard and for their implementation there are many materials, devices and equipment from which the developer chooses the best. However, if these same operations are carried out at negative temperatures in the Arctic, then there is a significant reduction in the range of the feasibility of technological operations.

| №  | Technological operations                  | Materials and terms of repair at room temperature | Materials and terms of repair at temperatures below -20°C | Correction factor for negative temperatures $k_i$ |
|----|------------------------------------------|-----------------------------------------------------|---------------------------------------------------------|-----------------------------------------------|
| 1  | Fitting the elements to be glued         | Standard technologies, equipment and tools for eliminating waviness of the connected elements | Special tools and equipment for mounting / dismounting at low temperatures | 0,9                                            |
| 2  | Surface preparation                       | Large selection of technological methods and a wide range of solvents | Only «cold» degreasing by rubbing with acetone or mixed solvents of grades P-4 and P-5 | 0,9                                            |
| 3  | PCM preparation                          | Standard technologies, equipment and tools for weighing components and mixing them | No technology available | 0,85                                          |
| 4  | Applying PCM to the surface being restored | Large range of tools and equipment for manual, mechanized and automated application | No technology available | 1                                              |
| 5  | Application of adhesive bonding          | Standard technologies, equipment and tools to exclude waviness of the connected elements during installation | Special tools and equipment for mounting / dismounting at low temperatures | 0,9                                            |
| 6  | Curing PCM                               | 24 hours at +20°C | 48 h at -20°C | 0,95                                          |
| 7  | Quality control                          | Standard control methods | No technology available | 1                                              |

Consider all the main stages of repairing machines using PCM and restrictions when performing repair work in conditions of negative temperatures.

Initially, mechanical fitting (leveling) of the contacting surfaces is performed in order to eliminate their waviness. This operation is usually performed manually using a mechanical tool. In terms of exposure to negative temperatures, the main restriction on the implementation of this operation are the requirements for the tool and equipment used.

When cleaning the surface at negative temperatures, such widespread methods as solvent vapor degreasing and immersion degreasing cannot be carried out. In the conditions of the Arctic, it is possible to perform only «cold» degreasing by wiping with a solvent. But most of the known solvents used during repairs (gasoline, white spirit) have a weak dissolving ability and their use is ineffective when the temperature drops below 0°C. Acetone and mixed solvents of grades P-4 and P-5, which...
allow surface preparation for gluing under negative temperatures, have a higher solvent capacity at negative temperatures. It should be noted that storage of solvents is allowed in unheated warehouses at ambient temperature not lower than -30°C. But degreasing is possible only if the temperature of the solvent is not below +15°C.

The following technological operation: the preparation of glue, can be carried out at low temperatures, subject to restrictions on the number of the prepared composition. It should be about 100-150 grams, which will allow materials to maintain their original viscosity value. Increasing the amount of glue will require more mixing time, which will also lead to a decrease in viscosity. The total duration of mixing should not exceed a few minutes.

When applying glue in the Arctic, it is quite difficult to ensure uniform thickness of the adhesive layer, since at temperatures below 0°C a quick change in the viscosity of the glue takes place, which makes it very difficult to apply evenly [12]. The introduction of special modifiers to the glue helps to solve this problem, which allows to increase the reliability of the glue at negative temperatures, which will not only reduce the viscosity build-up rate, but also regulate the kinetics of the curing process.

Installation (setting and application) of the surfaces to be glued at negative temperatures is performed only with the use of special equipment. Otherwise, during the cooling of surfaces, there will be a change in their linear dimensions (which will lead to the appearance of large defects during assembly) and icing (which will cause adhesives to lose their adhesive properties).

Curing is one of the most important final operations of the gluing process, during which all properties of adhesive bonding essentially depend. Lowering the temperature leads to a slowdown of all chemical processes, including the speed of the curing processes. As a rule, at temperatures lower than +5°C, the vast majority of adhesive materials do not fully cure. The use of special hardeners and modifiers allows for solving this problem [13]. Table 3 shows the dependence of the curing time of polymeric materials that are most widely used in the repair of machines in the Arctic on the ambient temperature.

| Ambient temperature during PCM curing, °C | Curing duration, hours |
|-----------------------------------------|-----------------------|
| -30                                     | 36                    |
| -10                                     | 30                    |
| 0                                       | 28                    |
| +20                                     | 24                    |
| +100                                    | 20                    |
| +120                                    | 14                    |
| +180                                    | 3                     |

It should be noted that the ambient temperature at which the adhesive material cures also has an effect on the shrinkage of the material. Table 4 shows the dependence of shrinkage of polymeric materials, which are most widely used in the repair of machines in Arctic conditions on the ambient temperature. The data is given for resin ED-20, in which a mixture of anhydrides was used as a hardener.

| Ambient temperature during PCM curing, °C | Shrinkage, % |
|-----------------------------------------|--------------|
| -30                                     | 0.3          |
| -10                                     | 0.5          |
| 0                                       | 0.5          |
| +20                                     | 0.5          |
| +100                                    | 0.8          |
| +120                                    | 1.2          |
| +180                                    | 2.0          |
The final stage of the repair process is quality control, which usually includes three stages: control of materials, operational control and control of finished products [14].

In order to take into account changes in the quality of repair when exposed to negative temperatures, this study proposes to use the integral correction factor (1), which allows you to take into account the effect of many factors that can affect the desired value both negatively and positively.

\[ K = k_1 \cdot k_2 \cdot k_3 \cdot k_4 \cdot k_5 \cdot k_6 \cdot k_7 \]  

(1)

where \( k_1 \ldots k_7 \) are coefficients that take into account the loss of quality at each individual technological operation. The indices of the coefficients \( k \) are given in accordance with the numbers of operations given in Table 2. The algorithm of working out repair technologies for manufacturability is shown in fig. 1.

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**Figure 1.** Flowchart demonstrating the process of technology selection for climatic manufacturability
The values of the coefficients of conservation of properties in table 2 were found by an expert method and are given, taking into account the optimal technological practices found earlier [12], but in this case there would be almost a 40% drop in quality

\[ K = 0.9 \times 0.9 \times 0.85 \times 1 \times 0.9 \times 0.95 \times 1 = 0.588 \]  

(2)

If additional testing of the technical process for climatic technological effectiveness is not carried out, then quality loss will occur not only in three technological operations (surface preparation, application and curing of PCM), but in all seven technological operations (see Table 2).

3. Conclusion

From the data given in table 2, the greatest quality losses occur during the preparation of PCM (operation 3, coefficient 0.85). This is primarily due to the fact that it is impossible to weigh the components outdoors at low temperatures and therefore graduated syringes were used as dispensers. The viscosity of the components of the adhesive at negative temperatures increases, which leads to the fact that part of the material remains on the walls of the vessel, which leads to improper dosing of the components.

The quantitative indicators of technological effectiveness include labor intensity, material intensity, energy intensity. In assessing climatic technological effectiveness, as well as in assessing the main quantitative indicators of manufacturability, a comparison of the new repair technology is made with a certain conditional reference, which is usually taken as a similar technical process, which is commonly called the base process (or baseline process). In this case, it is proposed to adopt a similar technical process performed at room temperature (under the conditions of a heated repair section) for the basic technological process.

This approach allows the use of common indicators (K coefficients), which allow to take into account changes compared to the base value, for example, at cost price (3) or applicability (4).

\[ K = \frac{C}{C_0} \]  

(3)

\[ K = \frac{\Pi - \Pi_0}{\Pi} \]  

(4)

In a similar manner, you can determine the values of the coefficients for reducing labor intensity, material intensity, energy intensity, etc.

In order to calculate the baseline indicators, it is advisable to use the method of correlation dependencies [9], which allows, using the available statistical data to establish a correlation between quality indicators and technological effectiveness indicators.

Thus, as a result of the research, it was proposed to use a new indicator, which is called climate adaptability in the work. This indicator allows to take into account the influence of climatic conditions on the quality of technological operations.

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