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Material selection for vehicle brake chamber case with using computer methods of analysis

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Abstract. In this paper, we consider options for using computer methods for analyzing the design features of some automotive units, which made it possible to justify the choice of materials and technologies for their manufacture. To improve the performance parameters that determine the service life of brake chamber housings made of a polymer composite material based on polyamide 6, methods for modifying the matrix are proposed that reduce its characteristic disadvantages - increased moisture absorption and a tendency to aging under the influence of atmospheric factors.

1 Introduction

Different types of software products for various functional purposes are used in modern mechanical engineering. To build traditional two-dimensional drawings that meet the requirements of standard documentation, AutoCAD and Compas computer packages are used, which allow us to form an in-plant base for the products being developed. The SolidWorks package is a multifunctional product that provides the design of parts and tooling, modeling of technological processes, the creation of control programs for machining centers, and the development of printed circuit board architecture. Based on advanced technologies of hybrid parametric modeling, the SolidWorks system allows us to create an accurate geometric model of the designed part with all dimensional and technological parameters [1, 13].

The top-level system is the Pro/ENGINEER Wildfire package, which is built on a modular basis and allows us to select modules that correspond to our tasks. The Pro/MECHANICA software product can be a built-in or independent module for performing Finite Element Analysis (FEA) analysis of the Pro/ENGINEER CAD/CAM system. Pro/MECHANICA STRUCTURE is a package for structural modeling and optimization of parts and structures.

Moldflow's Plastics Advisers products are used to model the process of filling a tooling volume with a polymer melt. This package allows us to evaluate the flow of the melt, based on ideas about the non-Newtonian behavior of the liquid phase. The resulting model representations are taken into account when optimizing the design of the part, choosing the material for the manufacture of the product and the technological parameters of its production, manufacturing tooling, and taking into account the design features of the

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product. The series includes software products Moldflow Part Adviser, Moldflow Metal Adviser, which determine the structure of the gating system, the technological parameters of the process: the time of filling the mold with the melt, the pressure drop across the section of the part, the distribution of the temperature field, the presence of a cold junction line and gas inclusions, quality surfaces, etc.

The most powerful program for analyzing and optimizing foundry processes is ProCAST [1]. This package allows us to calculate and visualize in a three-dimensional setting the process of flow and solidification of a material in a mold, analyze the resulting structure, assess the possibility of shell formation, porosity, residual stresses, and control the heat balance of the mold-casting system. The ProCAST system is built on a modular principle, each module of which performs a given functional purpose. The modules included in the system can correlate with various graphic formats and have a direct interface for two-way data exchange with Pro / ENGINEER, Unigraphics and finite element packages of various levels.

The presence of a large amount of software products allows for the optimization of design, technological and materials science solutions when creating various engineering products. At the same time, in domestic practice, the use of such products is very limited, and only single elements of CALS technologies are used to optimize automotive units [7].

It is obvious that when choosing materials and technologies for the manufacture of elements of automotive units, it is advisable to use software products to the maximum extent within the framework of the system approach, which allow developing the optimal solution, effective conditions for large-scale industrial production.

One of the options for solving the optimization problem of creating a brake chamber body is the use of composite materials based on polymer matrices, which can be used to manufacture structural and sealing elements, as well as functional coatings on the working surfaces of components.

Based on the above, researches for materials optimization for the construction of automotive and tractor units, due to high-tech composite materials based on polymer matrices, are very relevant.

2 Methods

The design of automotive units determines not only their functional purpose, but also their operational life. In some cases, despite materials using with high parameters of service characteristics for the manufacture of structural elements due to the specific conditions of their exploitation in combination with the features of the stress-strain state caused by the need to perform certain functions, destruction occurs, leading to a loss of operability of the unit as a whole.

Depending on the unit purpose, the optimal variant of its design is determined, providing the specified parameters of functional characteristics for a certain period of exploitation. At the same time, not only the functional purpose of the unit is taken into account, but also the manufacturability of its manufacture in mass production conditions, as well as technical and economic parameters that determine its competitiveness in the changing market of aggregates. This aspect is of particular importance when assessing the total operational resource of an automotive vehicle, which is not determined by the additive sum of the resource of the constituent aggregates. Moreover, the modern approach to the creation of a large range of automotive, agricultural and special equipment, based on the principle of "reasonable sufficiency", involves the use of unit designs with a certain service life, after which they are replaced without complex maintenance or repair, usually associated with significant material costs correlating with their the initial cost.

At the same time, the practical implementation of the "reasonable sufficiency" principle guarantees the consumer the unconditional fulfillment of functional parameters of the unit during a certain period of exploitation at a relatively low cost at the same time. Achieving such an optimization solution, including a combination of contradictory, at first glance, approaches, is possible with the use of modern computer tools, united by the concept of CALS technology [7, 12].

To analyze the manufacture features of brake chamber housings, an analysis method was used using computer packages for various functional purposes. Initially, with the use of Pro / ENGINEER, a three-dimensional model of the hull was built (Figure 1), which allows an assessment of the design features and to establish their imperfections.

Using the ProCAST casting simulation software, the kinetics of filling the working space of the injection mold with the flow of AK 12 melt was evaluated.

The analysis shows that the design features of the tooling (injection mold) and the brake chamber lead to local changes in the melt temperature, as a result of which the kinetics of crystallization processes in different parts of the product changes, which contributes to the formation of structural imperfections in the form of sinks. In addition, the high viscosity of the melt and the design features of the tooling lead to the formation of structural defects in the form of shells and through pores due to the imperfection of the air removal system from the working volume formed by the mold forming elements. This leads to the formation of so-called "gas bags" in various sections of the workpiece (Figure 2).

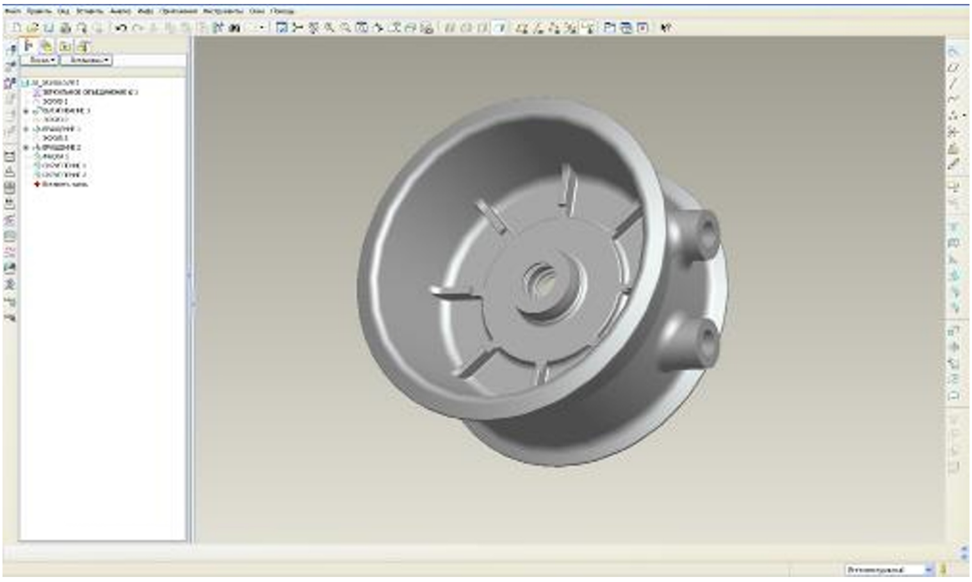


Fig. 1. Three-dimensional model of the brake chamber housing

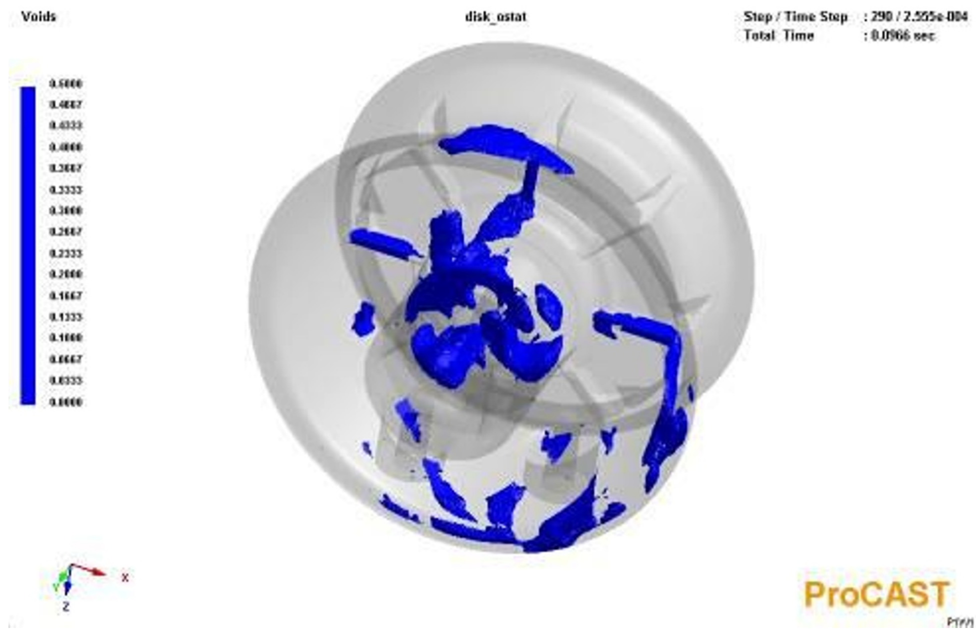


Fig. 2. The "gas bags" formation in the volume of the brake chamber casting

The design of the brake chamber body, due to its functional purpose, leads to uneven cooling of the melt in the working volume of the tooling and the appearance of thermal units in which the temperature exceeds the average value characteristic of various stages of the casting process. Due to the different thicknesses of individual sections, conditions are formed for the displacement of the gaseous components of the melt into local areas, which leads to the formation of shells in the volume of the casting with rather large geometric dimensions. The combination of "gas bags" and uneven cooling of various sections of the casting, which differ in geometric dimensions, leads to the formation of shrinkage porosity (Figure 3), causing a violation of the tightness of the structure. The location of the pores depends not only on the conditions of casting and the features of the workpiece, but also on the ventilation conditions of the tooling.

Considering the functional purpose of the housing, changing its design parameters is not possible without the loss of service parameters. Therefore, the most promising areas for improving the technological process of manufacturing the case are the selection of the composition of the base material with certain indicators of deformation-strength and rheological characteristics, which will reduce the unfavorable combination of casting parameters, product design and tooling design.

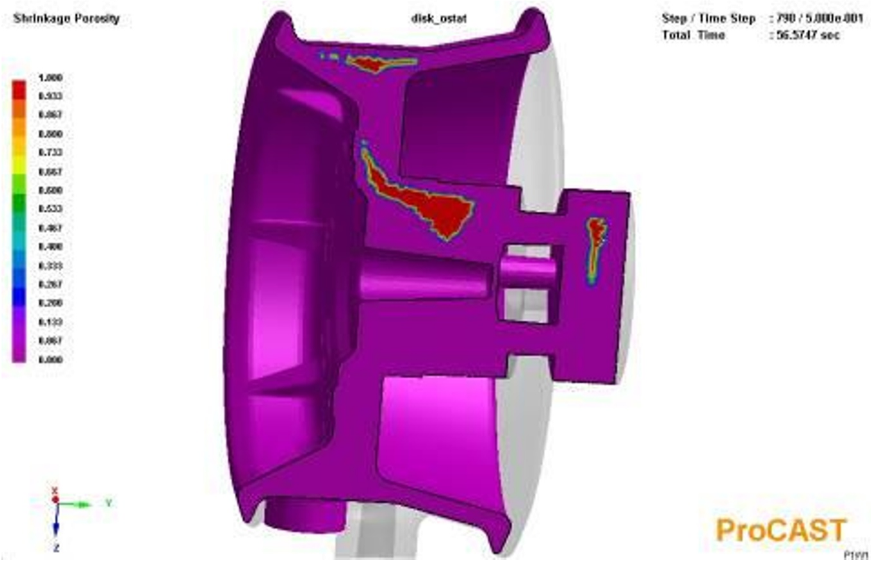
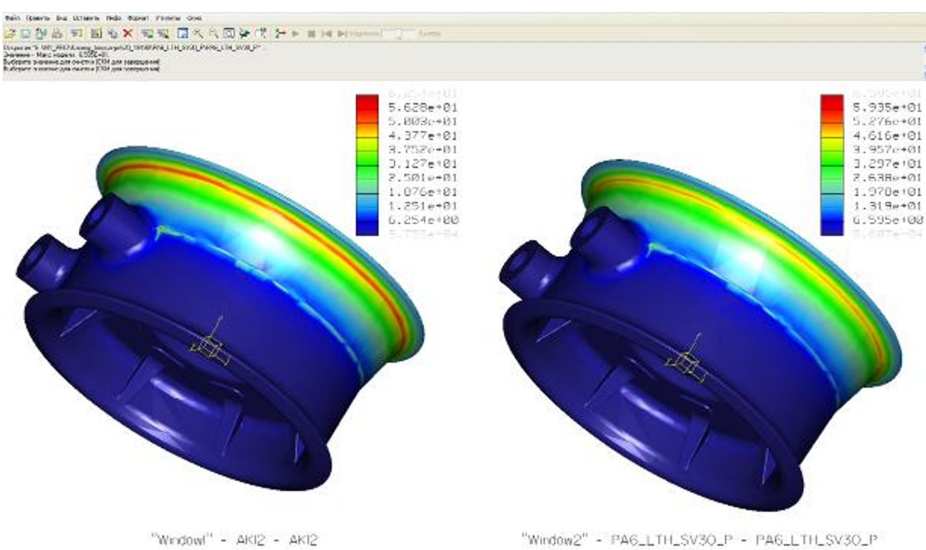


Fig. 3. Typical view of shrinkage cavities in various sections of the brake chamber casting

Using the analysis data given above, as well as a three-dimensional model of the case (Figure 4), an analysis was made from the possibility of using high-tech composite materials based on polymer matrices for its manufacture. The Pro/MECHANICA application of the Pro/ENGINEER software package was used for analysis.

The stress-strain state of brake chambers made of various materials was evaluated at a maximum force created by a spring of 20 kN with an estimated working force of 40 kN. Using a finite element mesh, the stress-strain state of blanks of brake chambers made of various materials, AK12, PA6-LTC-SV30-P, was assessed (Figure 4).



a) *b)*

FIGURE 4. Model of the brake chamber stress-strain state under the application of an axial load of 20 kN, made from AK12 alloy (a) and polyamide composition PA6-LTCh-SV30-P (b)

The analysis testifies to the practical identity of the results of modeling the stress-strain state of brake chambers made of various materials. The calculated maximum stresses arising in the glass-filled polyamide model do not exceed 59 MPa. According to the Mises-Hubert-Genka (MG) theory of fluidity, the critical state of a stressed structure occurs when elementary changes in the limit values determined by the expression

$$\sigma_{eq} = \frac{1}{\sqrt{2}}\sqrt{(\sigma_x - \sigma_y)^2 + (\sigma_x - \sigma_z)^2 + (\sigma_y - \sigma_z)^2 + (\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2)} \le [\sigma] \quad (1)$$

where:
σ_{eq} - is the equivalent voltages according to the MG theory;
$\sigma_x, \sigma_z, \sigma_z$ - main normal voltages;
$\tau_{xy}^2, \tau_{xz}^2, \tau_{yz}^2$ - main tangential stresses;
$[\sigma]$ - maximum permissible voltage.

For the PA6-LTCH-SV30-P brand polyamide products, the value was determined from the following expression:

$$[\sigma] = \frac{\sigma_t}{n} \quad (2)$$

where:
σ_t - is the tensile strength;
n - safety margin factor.

$$[\sigma] = \frac{155}{2} MPa = 77.5\ MPa$$

3 Results and discussion

For analysis, brake chambers of various designs used in the construction of trucks of the MAN, MAZ, KAMAZ, URALAZ, etc. series were selected to provide the necessary conditions for movement or parking braking.

With some differences in design, the manufactured brake chambers have common features due to established traditions in development, features of the technological equipment and materials used, which cause the formation of characteristic types of destruction and loss of performance of component parts.

Body parts made of aluminum alloys (AK 12) determine the performance of the entire structure of the brake chamber. The analysis showed that a significant part of the rejects is due to the imperfection of the technological process for manufacturing the brake chamber blank by injection molding. The design features of the brake chamber housing and the imperfection of the casting technology lead to the formation of through micropores and gas pockets, leading to loss of tightness.

Based on the results of comparing the parameters of the deformation-strength characteristics of the material used - AK12 alloy and promising polyamide PA6-LTC-SV30-P, it was concluded that this composition can be used for manufacturing the brake chamber housing by injection molding.

The technological parameters of this glass-filled polyamide brand were evaluated using the Moldflow Plastic Adviser software product.

For increasing the using efficiency of the composite polymer material, the design of the housing was optimized in such a way as to minimize the number of mechanical restoration.

After determining the optimal location of the intake channels using the parameters of an analog (Akulon J-7/3 Nalt composite material), the surface quality was assessed according to technological modes characterizing the time of filling the mold, injection pressure, and cooling rate. At the same time, the probable areas of maximum shrinkage, cold junctions, warping, and places of formation of gas bubbles were determined. The analysis results are partially presented in Figures 5 and 6.

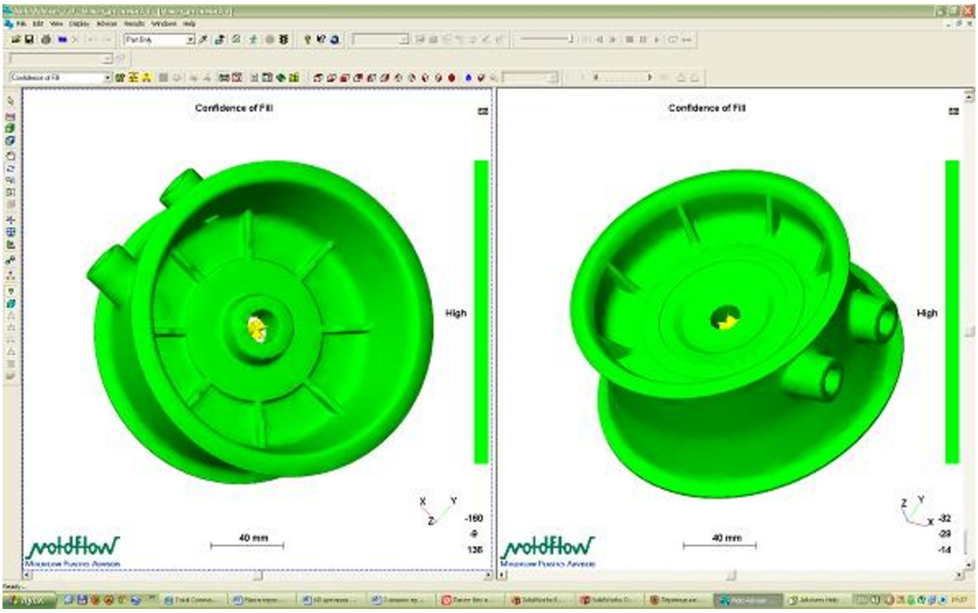


Fig. 5. Quality evaluation of the process of filling the working volume of the injection mold

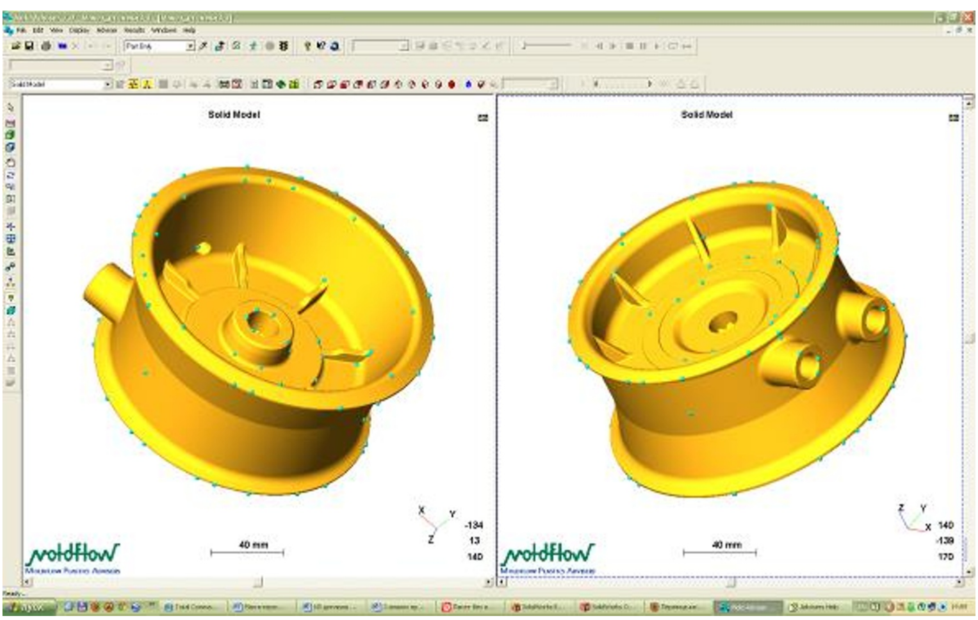


Fig. 6. Suspected places of gas bubbles occurrence

When assessing the process quality of filling the working volume of the mold (Figure 6) using the ‘Confidence of fill’ package and the expected places of gas bubbles occurrence according to the ‘Air trap locations package’, as well as other parameters that determine the quality of casting using various software products, it was found that there are no fundamental obstacles when using modern injection molding machines to replace the AK12 alloy with a composite polymer material: the working volume of the mold is filled evenly, without significant pressure drops, with uniform cooling, without significant defects in the form of cold joints and gas bubbles. Deviations of the geometric parameters of the product from the documentation do not have a noticeable effect on the parameters of service characteristics.

Thus, the analysis made it possible to determine the main reasons for the occurrence of defects in the manufacture of brake chamber housings by injection molding from aluminum alloy AK12 and to offer a full-fledged replacement of the composite, which provides quality improvement, reduction of defects and cost.

For increasing the parameters of service characteristics that determine the service life of brake chamber housings made from polymer composite material based on polyamide 6, methods of modifying the matrix are proposed that reduce its characteristic disadvantages of increased moisture absorption and a tendency to aging under the influence of atmospheric factors [2, 3]. An increase in the resistance parameter to atmospheric aging of the composite based on PA6 was achieved by introducing highly dispersed copper and polytetrafluoroethylene particles into the composition, obtained using the technology of thermogasodynamic synthesis (TGD).

Due to the adsorption interaction of active copper particles and fluorine-containing groups of macromolecules that are part of the products of ultrafine polytetrafluoroethylene (UPTFE) with the amide group, the probability of interaction of a polyamide macromolecule with air oxygen molecules decreases. Highly dispersed copper particles are formed in the melt of the composite during processing as a result of thermal decomposition of copper formate. According to the research results carried out in [4, 5, 6, 11], the optimal content of nanodispersed copper in the composition of the composite was determined, amounting to 0.05-0.2 wt.%.

The TGD synthesis products of polytetrafluoroethylene, as follows from the works [9], contain oligomeric fractions of various molecular weights, which are capable of homogeneous distribution in the matrix polymer with the formation of hardened regions [7, 8, 15]. Due to the manifestation of these processes, the composite's resistance to atmospheric aging and moisture absorption increases, which contributes to an increase in the operational life of composite housings to values characteristic of AK12 aluminum alloy housings (Figure 7).

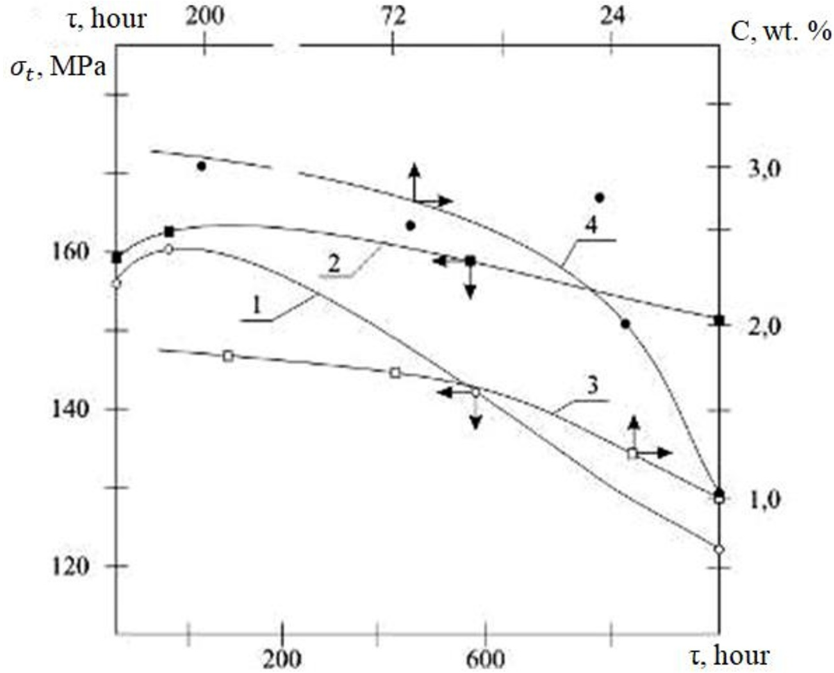


Fig. 7. The dependence of the destructive tensile stress σ_t on the thermal oxidation time at 250 °C (1, 2) and moisture absorption on the exposure time in water (3, 4) of polyamide PA6-LTCH-SV30-P of the original (1, 4) and modified 0.1 wt.%Cu and 1.0 wt.% UPTFE (2, 3).

4 Conclusions

Generally, the influence of structural and technological factors on the quality parameters of the brake chamber body has been established. The expediency of changing the design and replacing the material used with a composite polymer is shown.

The composite material composition of the brake chamber body structure of the cars is optimized using computer modeling methods. A computer analysis of the design was carried out according to the criteria of equal strength, manufacturability of the casting process and product defects.

Based on the principle of multilevel modification, the composite material composition based on polyamide 6 modified with glass fiber and a mixture of nanocomponents – copper particles and ultrafine polytetrafluoroethylene is proposed.

The developed composite material exceeds the basic composite in terms of resistance to aging and moisture absorption and is a full-fledged alternative to aluminum alloy.

The developed optimization design, technological and materials science solutions made it possible to recommend a composite material based on glass-filled polyamide 6 as an alternative to the imported analog - aluminum alloy AK12.

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