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The Development of a Mathematical Model to Optimize the Concentration of the Components of the Forming Adhesive Composition

U.R.Salomov, D.A.Moydinov, O.Z. Odilov

Doctor of Technical Sciences (DSc), Fergana Polytechnic Institute, Fergana, Uzbekistan
Doctoral student (PhD), Andijan Institute of Mechanical Engineering, Andijan, Uzbekistan
Doctor of Philosophy (PhD) in Technical Sciences, Fergana Polytechnic Institute, Fergana, Uzbekistan

ABSTRACT: The efficiency of motor vehicles (ATS) equipped with internal combustion engines (ICEs) is largely determined by the technical condition of the cooling system units, which maintains a given thermal mode of engine operation. One of the most heat-loaded units of the system is the radiator, the contamination of the internal and external heat-transfer surfaces of which leads to engine overheating, power loss, an increase in fuel consumption (by an average of 5-6%), detonation, and increased oil burnout. Overheating of the engine leads to increased wear of the elements of the cylinder-piston group and premature engine failure [1-5]. The only diagnostic parameter that indirectly reflects the influence of a large number of operational factors on the thermal regime of the internal combustion engine and can be measured while the vehicle is moving is the temperature of the coolant at the radiator inlet.

KEYWORDS: Adhesion, gradient methods, internal combustion engine, physical and mathematical models.

I.INTRODUCTION

Theoretical analysis of adhesives and their components made it possible to determine the binder, the type of hardeners and fillers required to obtain an adhesive composition for restoring the radiator core. The absence of a theory of adhesion does not allow having an analytical expression that allows one to determine the optimal concentration of components in the adhesive composition. To study such complex systems, which is the adhesive composition and the adhesive compound as a whole, which do not allow us to have an analytical expression for describing chemical and technological processes, we will use modelling. Modelling allows you to experiment on existing physical and mathematical models that have, with some approximation, the properties of the systems under study and their processes. Modelling allows you to reproduce the change in the state of the system, the development of processes, practically without resorting to field studies, to optimize their characteristics and to make a forecast [6-11]. The main purpose of modelling in the development of an adhesive composition is the choice of the optimal ratio of its components.

II. DEVELOPMENT OF A MATHEMATICAL MODEL

At its core, the study of technological processes and systems is based on the methods of mathematical and physical modelling. The approach to both methods is different. Mathematical models reproduce real processes and are displayed in the form of conventional mathematical symbols, and physical models are reduced or simplified to some extent real systems. Exact copying of the studied phenomena, the main requirement for physical models, which should be less complex than the actual object itself, otherwise the meaning of its use is lost. The physical model differs from other types of models primarily in that it retains the most essential, defining properties of nature, presented, as a rule, on a different scale. The use of physical models in the study of adhesive compounds and adhesives intended for the repair of machinery and equipment is complicated by the fact that it is practically impossible to reproduce the operating conditions of units and parts of cars and tractors, which are constantly changing, on the models. Therefore, in relation to the development of adhesive joints and adhesives, physical modelling is used only to obtain intermediate results, limiting itself, as a rule, to laboratory tests of adhesive joints in accordance with the available GOSTs. The final conclusion on the possibility of using the adhesive composition and the technology of its application is made based on operational tests [12-14]. When using physical models, they preserve the physical similarity to nature, touching not only the output characteristics but also the basic internal properties of the system. For mathematical models, as a rule, it is important to preserve only the semblance of the response of “exit” to “entrance”, therefore, mathematical models describe, as a rule, the structure of functional relationships between the varied composition of significant factors and the output quality of the process. In a mathematical model, "input" and "output" must be in mathematical equilibrium, the state of which can be both static and dynamic. The description of such systems is based on cybernetic ideas about the object of research. In this case, the object of research can be represented in the form of the so-called "black box" (Fig. 1), introduced by W.R. Ashby, the principles of construction of which correspond to the experimenter's a priori idea of the object of research in conditions of incomplete knowledge of the internal structure and mechanism of complex phenomena of the investigated process or system, which are the adhesive bond and the adhesive itself. This principle is very convenient for optimizing the concentration of the components in the adhesive composition [15-18]. Each arrow is assigned a corresponding factor, the sum of which forms the "input". In fig. 1, all the components that make up the adhesive composition will be denoted by arrows pointing towards the object. Arrows directed away from the research object characterize its quality. Each arrow corresponds to an optimization parameter, the set of parameters forms an “output”.

Figure 1.Black box.

We will apply to the inputs of the impact system by, varying, the concentration of the components included in the adhesive composition

$$X = \{X_1, X_2, ..., X_k ..., X_p\},$$

Where,

$$X_1 = \{X_{11}, X_{12}, ..., X_{li} ..., X_{lm}\},$$
$$X_k = \{X_{k1}, X_{k2}, ..., X_{ki} ..., X_{km}\},$$
$$X_p = \{X_{p1}, X_{p2}, ..., X_{pi} ..., X_{pm}\},$$

and observe the corresponding changes in the properties of the adhesive composition at the n outputs of the system

$$Y = \{Y_1, Y_2, ..., Y_k ..., Y_p\},$$

Where,

$$Y_1 = \{Y_{11}, Y_{12}, ..., Y_{lj} ..., Y_{ln}\},$$
$$Y_k = \{Y_{k1}, Y_{k2}, ..., Y_{kj} ..., Y_{kn}\},$$
$$Y_p = \{Y_{p1}, Y_{p2}, ..., Y_{pj} ..., Y_{pn}\},$$

Determination of the response of the system to its "output" can manifest itself only when a disturbance is applied to the "input". In our case, using mathematical models, we will express the functional relationship between the input parameters, which are the concentrations of the components of the adhesive composition, and the output parameter, the value of the maximum compressive stress, which is shown in figure [2].

Figure 2.Scheme of the mathematical model, optimization of the concentration of the components of the forming adhesive composition.

Where, X_2 - binder (ED-20),X_2 - hardener (ТЭТА),X_3- filler (copper powder, talc), y - optimization parameter (maximum compression stress).
In this case, the type of statistical relationship will be determined by conducting a certain set of experiments. In general, the form of the functional relationship between "input" and "output" can be expressed as a function.

$$y = f(x_2, x_2, ..., x_2)$$

The presented expression characterizes the response surface in a certain vector space. The exact functional relationship of the process under study is unknown to us. In cases where, along with linear effects, the significance and effects of interactions are assessed, the regression equation for three factors will look like this:

$$y = b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{123}x_1x_2x_3$$

where$y$ - the optimization parameter;
$x_1x_2x_3$ - factors that vary during the experiment;
b_1,b_2,b_3 - coefficients of regression of one factor for linear terms of interactions;
$b_{12}b_{13}b_{23}$ - regression coefficients of two factors for linear terms of interactions;
b_{123} - the coefficient of regression of three factors for the linear terms of interactions.
By the value of the regression coefficients, we will judge the degree of influence of the change in the mass fraction of the glue components on the value of the breaking compressive stress.
There are no uniform indicators for assessing adhesives. In each specific application, one or more basic requirements are developed. In this case, you can simultaneously examine several output parameters, while for each optimization parameter there will be its own mathematical model (response function). Optimization of the concentration of the adhesive composition.

III. METHODOLOGY

In the process of searching for the optimum in experimental research, various methods are used. The search for the optimum does not cause difficulties if the goal function is specified in an analytical form and is not very complicated. In the presence of an analytical function, the coordinates of the optimal region or point are found by differentiating the corresponding equations, equating the derivatives to zero, and solving the resulting system of equations. It is not possible to develop an adhesive composition and optimize the concentration of its components using analytical dependencies. This is due to the lack of a theory of adhesion and analytical dependencies that allow evaluating the effect of fillers on the properties of adhesive compositions. In such cases, one has to look for an approximate solution [19-22]. For this case, nonlinear programming methods can be successfully used, which are subdivided into the following groups: gradient methods; no gradient methods; random search methods and combined methods, combining some of the advantages of individual methods from different groups. For the development of the adhesive composition, the gradient method of finding the optimum is more suitable, which is based on the use of mathematical models that approximate the target functions and on the analysis of their partial derivatives.
The gradient of the objective function at the point under consideration is a vector that is directed along the normal to the surface of a constant level and is equal in algebraic value to the derivative of this function. The specified vector at each point of the domain of definition of the target function is directed along the normal to the surface of a constant level drawn through this point and therefore coincides in the direction with the fastest decrease or increase in the objective function. Therefore, the movement to the optimum along the gradient is performed along the shortest path,

which allows not only to reduce the number of experiments but also to obtain specific values of the concentration of each component in the adhesive composition. In general, the gradient of the objective function.

$$y = f\left(x_1, x_2, \dots, x_\kappa\right),$$

there is a vector,

$$\text{vy}=\frac{\partial y}{\partial \text{x}1}\text{i}+\frac{\partial y}{\partial \text{x}2}\text{j}+\frac{\partial y}{\partial \text{x}k}\text{k},$$

where, *vy* - designation of the gradient;

$\frac{\partial y}{\partial \text{x}1}; \frac{\partial y}{\partial \text{x}2}; \dots \frac{\partial y}{\partial \text{x}k},$ - partial derivatives of the function with respect to the *i* - th factor;

i, j,...,k - unit vectors in the direction of the coordinate axes of the factor space.

The components of the gradient are the partial derivatives of the response function. To move along a gradient, which makes it possible to reduce the number of experiments, we will change the concentrations of their components of the adhesive composition according to the regression coefficients in the direction indicated by the sign of the coefficient. The values of the components of the gradient are determined by the shape of the response surface. The sign of the gradient components depends only on the shape of the response surface and the position of the zero point.

IV. RESULTS

Computer programs as a modelling base for the development of adhesive compositions. The life of modern society is largely due to the development of computer information technologies. They permeate all spheres of human activity; ensure the functioning and evolution of the modern social organism. The human mind itself is not adapted to the direct deep perception of arrays of numbers and cannot extract complete information from data. Therefore, in the modern world, the ability to use computer data processing systems has become necessary for successful activities in any field. Knowledge of such programs is now a mandatory element of erudition. The modern market for computer data processing programs is vast and diverse, with over a thousand products represented. Such a variety of computer programs reflects the diversity of processing tasks in various areas of human activity.

Reviews of these programs are given in special reference books, which contain brief descriptions of their purpose, requirements for the technical characteristics of a computer, information about additional service capabilities, prices and addresses of suppliers. These are very voluminous publications published in the Western press. However, it should be noted that a significant part of the published information quickly becomes outdated, which is associated with the rapid pace of development of the industry. Periodically held domestic and international seminars and conferences on data analysis help to track the transformation of the processing software market. Available for domestic users are the programs Mathcad, S-PLUS, SYSTAT, SPSS, STATISTICA, SAS, Visual Numerics

The listed programs have many overlaps in the composition of statistical procedures. In addition, modern versions of programs have, as a rule, a modular structure, which allows significant cost savings. The Windows interface of the latest versions of the packages largely unifies the user interaction with analytical, graphical and system procedures. In addition, the dialogue is organized differently. The functionality of the packages also varies, here STATGRAPHICS Plus for Windows stands out for the better. The first version of this program was released in 1994 by Manugistics and Statistical Graphics corporations. STATGRAPHICS Plus for Windows includes more than 250 statistical and system procedures used in business, economics, marketing, medicine, biology, sociology, psychology, manufacturing and other areas.

The whole package has a modular structure as a whole. Each group has its menu. The following procedures function in the basic system:

The Describe menu contains statistical methods of analysis for one and many variables, procedures for fitting distributions, tools for tabulation and cross-tabulation of data;

The Compare menu includes methods for comparing two or more data samples, procedures for one- and multivariate analysis of variance;

The Relate menu contains simple, polynomial, and multiple regression analysis routines. The basic system includes a fairly complete set of the most common types of statistical data analysis. At the same time, to expand the capabilities of the system, additional modules are offered, the initialization of which is carried out through the Special menu. These include the Experiment Planning module, which, in our opinion, can be used to optimize the concentration of the components of the adhesive composition. According to the description of the program, the module "Planning an experiment" helps to formulate the criterion of the optimality of the experiment plan, to choose the best plan, to organize the collection and processing of the required information. When working with this module, the user does not need to worry whether he knows much or little about the planning of the experiment. The module offers effective ways to simplify and integrate knowledge about the process under study. The procedure for interacting with the module is as follows: determination of factors; choice of a plan; generating a worksheet for collecting and recording data; selection of a model; interpretation of results. Taken together, this results in faster research times, lower overall costs, and overall increased productivity.

V.CONCLUSION AND FUTURE WORK

Analysis of theoretical calculations and designs of radiators showed that even though the use of the proposed method provides for a decrease in the area of the cooling surface of the radiator, the initial parameters for calculating the radiator allow you to repair a certain percentage of the radiator area using the proposed method. The permissible percentage of the repair area must be determined experimentally. The heat transfer of the repaired section of the radiator core can be increased by increasing the thermal conductivity of the adhesive. The highest thermal conductivity is possessed by polymer systems filled with aluminium and copper powders, as well as boron nitride. With an increase in the content of these fillers, the thermal conductivity of the polymer system also increases linearly. Analysis of existing hardeners shows that due to the hardener, the heat resistance of the adhesive composition can be increased to + 128 ° C, which will ensure the performance of the adhesive composition when used to repair the core of an internal combustion engine radiator.

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