Investigation of the dependence of the quality control of the adhesive joint on the capacitance of the joint for various types of dielectric

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Abstract. The control of adhesive joints is a mandatory step in the process. However, at present, there is no device that could be used at various stages of production. The main part of the devices allows you to control finished products. The developed method is based on the use of measuring the electrical parameters of a compound to control the quality of this compound. The essence of the method is as follows. An article containing glued elements measures one of the electrical parameters: capacity or resistance. The obtained value is compared with the theoretical value of this parameter calculated and set as “tolerance”. If the measured value is within the tolerance, then a conclusion is drawn about the suitability of this adhesive joint; otherwise, the connection is rejected. The data obtained allow us to conclude that there is a relationship between the measurement of the capacitance parameter of the compound and the thickness of the dielectric layer. However, for it is necessary to study in depth how this method behaves when working with other dielectrics and a relationship is traced between them. The processing of resistance measurement data also shows that the use of data on this parameter is possible, but with stabilization of the measurement conditions, since a stronger discrepancy with the theoretical (calculated) values was observed during the measurement.

1. Introduction

Adhesively bonded joints are an increasing alternative to mechanical joints in engineering applications and provide many advantages over conventional mechanical fasteners. They provide a more uniform stress distribution along the bonded area which enables to have a higher stiffness and load transmission, reducing the weight and thus the cost. Due to the polymeric nature of the adhesive, adhesive joints provide good damping properties which also enable to have high fatigue strength [1]. For example, a study was conducted that showed that the use of film adhesives can increase the vibration damping properties of a sandwich panel structure (it is two 0.4 mm thick steel sheets joined by 0.15 ... 0.20 mm film adhesive) several times over compared with ordinary steel sheet (steel sheet with a thickness of 1 mm and a size of 665x300 mm) [2]. Applications related to adhesive bonding are today very diverse and can be found in virtually all types of industry. The aeronautical industry is one of the precursors of this technology and increasingly uses adhesives as more composites are introduced in airplanes. The rail and automotive industry is also turning to adhesives to produce lighter vehicles. Civil construction, shoes, and electronics are other examples [1].
2. Samples of the hypothesis
The use of adhesive joints entails a number of unsolved problems, which are the basis for numerous development and research. So, adhesive joints are limited by operating conditions at high temperatures and high humidity; a number of problems are associated with the preparation of surfaces before gluing and the method of fixing the surfaces relative to each other, as well as the exposure conditions necessary for the glue to transition to a “working” state. But the solution to the problem of quality control of such compounds remains one of the most popular.

Today, there are many methods for controlling adhesive joints based on the use of radioactive and X-ray radiation, acoustic and ultrasonic resonance, electron microscopy, electron emission, infrared and laser radiation, holography, measurement of electrical resistance and permittivity, and measurement of thermal conductivity.

However, the unresolved issue of creating such a device or non-destructive testing method that would be suitable for use in a production environment. That is, monitoring the bonding of not the finished product, but its individual components or monitoring at certain stages of the process. Most of the methods used are unsuitable for solving this problem. Some methods require special conditions for the measurement, to use others, special protective equipment and a certain high level of training of the specialist conducting the monitoring are required.

To solve this problem, to develop a control method suitable for use at various stages of the technological process of manufacturing and assembly of adhesive joints, in Bauman Moscow State Technical University is developing a control method based on the use of electro-capacitive and electroresistive measurement methods.

Its essence is as follows. An article containing glued elements measures one of the electrical parameters: capacity or resistance. The obtained value is compared with the theoretical value of this parameter calculated and set as “tolerance”. If the measured value is within the tolerance, then a conclusion is drawn about the suitability of this adhesive joint; otherwise, the connection is rejected.

When conducting this study, the theoretical value of the capacitance was taken to be the value calculated by the classical formula of a flat capacitor:

$$C = \frac{\varepsilon \varepsilon_0 S}{d},$$

where $\varepsilon$ – adhesive dielectric constant;
$\varepsilon_0$ – electric constant;
S – capacitor plate area;
d – distance between plates.

The calculation of resistance was carried out according to the formula:

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC},$$

where $\omega$ – cyclic frequency;
C – capacity.

It can be seen from the formula that the capacitance directly depends not only on the geometric parameters of the compound, but also on the physicochemical properties of the dielectric.

Two main factors affect the choice of adhesive material: the operational reliability of the adhesive joint, which characterizes its quality; economic feasibility, which is measured through the cost. The final decision on the choice of adhesive material is made after a series of bench tests, the conditions for which are as close as possible to the operating conditions of the adhesive structure [3].
3. Research results
To refine the measurement in this study, an adhesive based on high molecular weight polyethylene, polyvinyl chloride, rubbers, and other high-tech materials was chosen as the adhesive material. The main selection criteria were the availability of this adhesive, its ability to act as a dielectric, and the possibility of repeated use. The role of the capacitor plates was performed by two metal steel plates. The scheme of the sample is shown in Figure 1.

![Figure 1. The plane of the sample for the experiment](image)

The surface of the plates was completely covered by a dielectric. This was necessary in order to determine the contact area and the thickness of the dielectric as accurately as possible. A series of measurements was carried out, at which different thicknesses of the dielectric layer were formed, and theoretical values of the capacitance and resistance were calculated using formulas (1) and (2). The calculated values are given in table 1.

| Dielectric layer thickness, mm | Estimated value of capacitance, pF | The calculated value of resistance, MΩ |
|------------------------------|-----------------------------------|--------------------------------------|
| 1 1,493                      | 41,81                             | 77                                   |
| 2 1,693                      | 33,66                             | 98                                   |
| 3 2,003                      | 24,98                             | 134                                  |
| 4 2,753                      | 21,35                             | 258                                  |
| 5 3,456                      | 19,09                             | 355                                  |

The next step in conducting the study is to measure the sample. Resistance and capacitance were measured using an R L C immitance meter E-27. Each sample was measured many times, then the arithmetic average of the measurement of each parameter on each sample was calculated. The measurement data are shown in table 2.

| №  | Dielectric layer thickness, mm | The measured arithmetic mean value of the capacitance, pF | The measured arithmetic mean value of resistance, MΩ |
|----|--------------------------------|--------------------------------------------------------|-----------------------------------------------------|
| 1  | 1,493                          | 40,19                                                  | 79,24                                               |
| 2  | 1,693                          | 35,44                                                  | 89,80                                               |
| 3  | 2,003                          | 26,08                                                  | 122,11                                              |
| 4  | 2,753                          | 21,79                                                  | 146,15                                              |
| 5  | 3,456                          | 17,36                                                  | 183,45                                              |
Based on the received data, we construct a graph for a visual image of the received data.

**Figure 2.** The dependence of the capacitance on the thickness of the dielectric layer.

From the data obtained, it can be concluded that there is a relationship between the measurement of the capacitance parameter of the compound and the thickness of the dielectric layer. However, for it is necessary to study in depth how this method behaves when working with other dielectrics and a relationship is traced between them.

**Figure 3.** The dependence of the resistance on the thickness of the dielectric layer.

Processing the data of resistance measurements also shows that the application of this method is possible, but with stabilization of the measurement conditions, since when measuring this parameter, a stronger discrepancy was observed with theoretical (calculated) values.
4. Conclusion
We considered the case when surfaces are interconnected by materials that are dielectrics in their properties. However, in various fields of technology, it is required to ensure electrical contact between the surfaces to be joined by using electrically conductive adhesives. Such adhesives are most in demand in instrumentation and electronics. In aircraft and rocket science they are used in adhesive joints of structures to remove static electricity [4].

Therefore, it is necessary to consider and examine samples connected by an electrically conductive adhesive. Specialized sources suggest that adhesives with the introduction of powdered silver with spherical particles ranging in size from 0.1 to 3.0 microns in combination with a powder having a scaly form of particles have the most optimal characteristics. As a filler of conductive adhesives, which should be used in aggressive environments, powdered gold is used.

In the future, in accordance with the research program, it is planned:
1. Compare different types of conductive adhesives and their operating conditions, choosing the optimal and universal for the experiment;
2. Assess the geometric parameters of the samples;
3. Assess the degree and nature of the influence of geometric parameters on the measurement results;
4. Assess the degree of influence on the measured parameters of the chemical-physical properties of the adhesive material.

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