Multivariate system for evaluating the glue-welded joints quality

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Abstract. The change in quality indicators when replacing traditional welded joints with glue-welded ones is considered. The classification of factors influencing the machines glue-welded joints destruction processes is given. The possible destruction causes are shown on the base of the glue-welded joints destruction nature analysis. The cause-and-effect relations that have the greatest impact on the quality when replacing traditional machines welded joints with glue-welded ones are established.

1. Introduction
The glue-mechanical (glue-welded) joints are widely used for assembling a wide variety of components and aggregates of construction and road machines and mechanisms. Their distinctive feature is the combination of bonding technology and contact welding in a single technological operation, which makes it possible to obtain compounds with significantly higher characteristics under long-term alternating strength and thermal loads [1-2].
Currently, glue-welded joints are used in the manufacturing and repair of a large range of space-box machines structures.
Glue joints, as well as glue-welded joints, refer to simple systems with a small number of variables, which include the geometric dimensions and substrates material, the glue and the welded point, with their geometric dimensions and characteristics. This approach has been widely used [2-6], but it does not allow to make reliable forecasts for durability, since it does not consider the influence of subjective factors that can change all the characteristics of the glue-welded joint radically. In the considered subject area, such basic subjective factors include technology, or more precisely, technological errors that occur when performing any technological operation.
Technology is the only quality management tool, but there is no specific rating system for it, which is associated with a huge variety of physical, chemical and mechanical factors. Currently, most researchers study the influence of one or more factors on one of the quality indicators, for example, the authors [7-10] investigate the influence of the adhesive material chemical nature on the thermophysical and tribological characteristics of finished parts. This approach allows to optimize the glue composition for a specific purpose, but does not allow to make reliable forecasts for any changes in the experimental conditions. In [11-14], the authors focused their efforts on determining the filler structure contribution to the complex properties of the resulting materials, but the obtained results are valid only for one scale level (macro level) and cannot be used if a similar comparison is required for the same systems at the micro- or nanoscale. A large number of works is devoted to the technological modes study, for example, the authors of works [15-17] studied a variety of technological operations and made attempts to optimize technological parameters, but the obtained results can only be applied selectively in a narrow field.
Thus, numerous studies, as a rule, are random in nature, which is due to the fact that their authors were forced to solve specific technological problems. All this doesn’t allow to develop common approaches to the quality assessment system when the traditional welded joints are replaced with glue-welded ones. The purpose of this work is to determine the cause-and-effect relations that affect the quality the traditional welded joints are replaced with glue-welded ones.

2. Results and discussion
The three groups of quality indicators of machines glue-welded joints may be distinguished conventionally (Table 1):
• purpose indicators (strength, rigidity, structural characteristics, corrosion resistance);
• technological performance indicators (assembly accuracy, possibility of the technical process automation, possibility of assembly at subzero temperatures);
• economic indicators (material consumption, energy consumption, labor intensity).

The glue-welded joints have a higher strength with uneven separation and shear from the point of view of purpose performance. The shear strength of glue-welded joints is defined as the strength of the welded point multiplied by a factor of 1.25 ... 2, which considers the work of the glue [2]. When loading the glue-welded joint, the adhesive seam takes a significant part of the stress, unloads the welding points and reduces the sheets deformation. The stress concentration over the cross-sectional area not only decreases in a glue-welded joint, but also equalizes and increases the joint strength, especially under cyclic loads.

The methods of creating glue-welded joints are somewhat inferior to similar welding technologies in terms of technology. The adhesive material has an ambiguous effect on an assembly performance. On the one hand, it provides a significant increase in the actual contact area of the heating parts, which is associated with the undulation and roughness of the connected surfaces [2, 10]. On the other hand, it provides an increase in the tightness, joint strength and stiffness characteristics.

The economic indicators analysis shows that the use of glue-welded joints in the machines production and repair increases the labor intensity and material consumption, but at the same time reduces the energy intensity. This is due to the fact that the number of welding points is reduced in the production of machines using glue-welded joints (up to 40%), compared with a similar welded structure, which leads to a cost reduction.

**Table 1. The quality indicators comparison of machines welded and glue-welded joints**

| Name of quality indicators | Connection type                  |
|----------------------------|----------------------------------|
|                            | Welded, %                        | Glue-welded, %                  |

**Purpose indicators**

|                         |                        |                  |
|-------------------------|------------------------|------------------|
| Strength                | 125                    | The glue works as a construction material between two adjacent points |
| Rrigidity               | 150                    |                  |
| Structural characteristics | 80                    | The glue layer welding process is less stable than traditional assembly, which leads to an increase of the near-seam zone length and the dent depth |
| Corrosion resistance    | 300                    | The glue protects the metal from corrosion between the welding points reliably, completely prevents crevice corrosion |

**Technological performance indicators**

|                         |                        |                  |
|-------------------------|------------------------|------------------|
| Assembling accuracy     | 100                    | Does not change in compliance with the technological process |
| The ability to automate the technical process | 110 | It is necessary to organize an additional workplace for applying glue; organization of an additional operation for glue curing and the availability of equipment for mechanizing the glue supply |
| Ability to assemble at subzero temperatures | 100 | It is possible without quality deterioration when the appropriate adhesive materials are chosen and the modes are adjusted |

**Economic indicators**

|                         |                        |                  |
|-------------------------|------------------------|------------------|
| Material consumption    | 100                    | Additional costs for the glue purchase |
| Labor intensity         | 100                    | Additional operations for applying the adhesive material and removing its excess |
As a rule, there is a complex nature of damage, in which the sum of different factors affects the machines glue-welded joints. It leads to corrosion, tightness loss, reduced rigidity and other damage.

A distinctive feature of the traditional welded and glue-welded machines joints destruction is the variety of situations in which they are operated. This makes it much more difficult to create adequate mathematical models that would consider all the variety of real factors and mechanisms of their influence. Thus, the multivariable nature of the destruction processes is the main reason why now there are no standard approaches to describing the destruction mechanisms of machines glue-welded joints.

The development of destruction processes depends on the physical and chemical interaction of all the components of the glue-welded joint, which include: the welded point, the connected parts, the adhesive material and the degree of its adhesive interaction with the parts.

It is possible to distinguish four main types of glue-welded joints destruction (figure 1), having determined which it is possible to draw a preliminary conclusion about the causes of destruction [4, 18]:

- adhesive (figure 1, a);
- cohesive on the glue and the welded point (figure 1, b);
- cohesive in the material of the connected parts (figure 1, c);
- combined, when all types of destruction are present (figure 1, d).

The main part of the adhesive material remains on one of the connected surfaces during the adhesive destruction of the glue-welded joint. This indicates an incorrect surface preparation or an adhesion lack between the adhesive material and one of the connected surfaces.

A preliminary conclusion can be made that the adhesive material is correctly selected (since there is a good adhesive strength between the glue and the connected surfaces), if there is a predominance of cohesive failure on the glue and the weld point. Ideally, the glue-welded joint destruction should occur exactly according to this type. But if the destruction occurred at loads which are significantly lower than the calculated ones, this may indicate a violation of the assembly technology (layer thickness, welding modes, glue curing modes, etc.).

![Figure 1](image-url)

**Figure 1.** Types of glue-welded joints destruction: adhesive destruction (a), cohesive on the glue and the welded point (b), cohesive on the material of the connected parts (c), combined (d)

A preliminary conclusion can be made that the strength of the glue-welded seam significantly exceeds the connected parts material strength if the part material cohesive destruction prevails.
With a destruction combined nature, it is necessary to determine which type of destruction prevails, and draw appropriate conclusions. The differences in the destruction nature of the traditional welded and glue-welded joints allowed us to establish the most important advantages of adhesives, the use of which leads to the stress’s equalization along the cross-section. Thus, there is a reduction in the maximum stresses that are distributed from the area of the weld point along the entire length of the adhesive seam. As a result, such compounds are characterized by significantly greater fatigue strength. Identification of the fatigue damage nature is also usually carried out on the basis of the analysis results. The factors that have the greatest influence on the glue-welded joints destruction can be divided into 5 groups (figure 2) [1-2, 18]:

1. Quality of the adhesive joint (including damage of the adhesive joint after welding);
2. The welding quality of the glue layer;
3. Operational factors (operating conditions: temperatures and their variation range, amplitudes and loads application frequency);
4. Load application conditions (loading processes unsteadiness);
5. Time factor.

![Factors influencing the processes of glue-welded joints destruction](image)

Figure 2. Factors influencing the processes of glue-welded joints destruction

Each group of factors will be considered in detail. The adhesive material used to create the glue-welded joint must meet the following requirements to minimize the factors related to group 1:
- minimum number of structural defects;
- high deformation and thermophysical properties (to ensure minimal damage of an adhesive seam during welding);
- the adhesive strength of the adhesive material system – the connected surfaces material must be as high as possible and stable for a long time under the influence of operational factors.

The durability of glue-welded joints during operation depends not only on the glue properties and the connected materials, but also is determined by the boundary layer to a significant extent, which is also called interfacial. It is very difficult to determine experimentally most of the characteristics of the interfacial layer (its geometric dimensions, hardness, porosity, etc.). That’s why the structural methods for studying fracture surfaces have become so widespread.

In the 2 group of factors, the quality of the used materials, compliance with the alignment of the welding points, compression force and technological modes (time, temperature, etc.) have the greatest influence.
The resistance of machine structures to the impact of operational factors (the 3rd group) is most often studied in relation to one of the factors, working media (water, technical liquids), anti-icing reagents, strength under static and dynamic loads, etc. This is due to the fact that each of these factors has its own standardized test methods.

Various working media (technical liquids, water, etc.) destroy the adhesive joint interface, which leads to a sharp drop in its strength. The decrease in strength due to the impact of working environments also leads to a change in the nature of the failure, which becomes adhesive. Water and various technical liquids can also be adsorbed directly by the adhesive material itself, which can lead to a significant loss of its strength and in this case the nature of the destruction will be cohesive to the glue. The epoxy adhesives have the greatest resistance to water and technical liquids among the structural adhesives used in the assembly of metal structures. It is known about epoxy adhesives that the decrease in strength when holding glued samples in cold water for 30 days does not exceed 15% [6].

All materials used as de-icing reagents are also considered hazardous operating factors for welded and glue-welded machines joints. They penetrate into joints and crevices, they are very difficult to remove using standard cleaning methods, and as a result, corrosion in such joints develops significantly faster than in open areas.

The value of the fatigue point is used as a rule for evaluating the factors of the 3rd group in engineering calculations. The fatigue point is the highest stress, the repeated application of which does not cause the destruction of the connection in its given state after a certain conditional number of cycles. For glue-welded joints, the fatigue point is usually 20 ... 60% of the static failing stress. The introduction of various fillers into the composition of the adhesive materials used in the creation of glue-mechanical compounds leads to a significant increase in the fatigue point.

In the 4th group of factors, a very large influence on the strength and durability of glue-mechanical joints is exerted by the frequency of loads application and the unloading duration (the joint rest time). If there is a certain time period between the loading and unloading cycles, then during this time there is a stress relaxation and a subsequent loading cycle.

The fatigue material destruction occurs under the influence of factors of the 5th group (time factor). Fatigue (or fatigue point) characterizes the joint durability and is determined not only by the adhesive material properties and the joint type (rivet, weld point), but also by the geometric shape of the connected surfaces, and also largely depends on its interaction with adjacent elements (on the node design). Fatigue failure is the result of multiple deformations, which, due to the joint heterogeneity, are distributed unevenly. The fatigue processes are closely related to aging processes for glue-mechanical joints.

3. Conclusion
Thus, a comprehensive quality indicator of glue-welded joints consists of purpose indicators, technological performance indicators and economic indicators. The change in quality indicators when replacing traditional welded joints with glue-welded ones has been considered. It has been shown that the glue between two adjacent welding points works as a structural material. It protects the metal between the welding points from corrosion reliably, and completely prevents crevice corrosion. But at the same time, there is a slight deterioration in the structural characteristics and economic indicators – material consumption and labor intensity.

It has been shown that the nature of the glue-welded joints destruction, as a rule, passes through one of the four described options: adhesive destruction, cohesive on the glue and the welded point, cohesive on the material of the connected parts or combined. The possible causes of destruction and cause-and-effect relations that have the greatest impact on the quality, when the traditional welded joints are replaced with glue-welded ones, are shown based on the analysis of the nature of the glue-welded joints destruction.

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