

The object of this study is the technology of bus bodies and the formation of recommendations for design body-work subject to the regulated durability of the body introduced into production. Advancing the technology of manufacturing bus bodies implies improving anti-corrosion protection, using new polymeric materials, and reducing the length of welds.

The issue of corrosion resistance of bus bodies has been considered. It is established that the use of new polymeric materials will increase the corrosion resistance of bus bodies while existing technologies weakly protect against corrosion (resource up to 5 years). The peculiarity of this study is that the adhesion of new materials has been tested, with artificial aging, which confirms the durability of glued joints.

According to the old technology, the body was exposed to anticorrosive treatment after welding the cladding with uncovered places left between the frame and body cladding, which provoked corrosion. The main idea is that in the new technology, the cladding is welded or glued after the body frame is fully coated with primer.

New technologies and materials not used in the automotive industry have been proposed. Three variants of technologies were put into production. First: the welding of steel zinc sheets. In welding sites, the frame is covered with conductive primer. It was implemented for school buses (after 7 years, without damage). Second: gluing steel zinc sheets. It was implemented for city buses (after 6 years, without damage). Third: gluing sheets from composite materials not used in the automotive industry. The transition to new adhesive cladding technologies from composite corrosion-resistant materials instead of steel sheet, reduces by 2.5–3 times the length of welds (up to 20 years without damage).

The studies have confirmed the strength of glued joints (cohesion rupture exceeds 95 %). The reliability of glued joints and high corrosion resistance of the body have been confirmed in the operation of buses.

The scope of practical use of the results: bus-building plants.

The reported results are suitable for production of all types while cathodic coatings are only for mass production.

Keywords: bus, body, corrosion, corrosion protection, new technologies, adhesion, adhesive mixtures, aluconbond, glued side panels

DEVELOPMENT OF BUS BODY TECHNOLOGIES IN TERMS OF CORROSION AND DURABILITY

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1. Introduction

Taking into consideration the current trends of bus construction, public transport buses require constant improvement of the design at a competitive adequate cost. Buses must comply with UNECE Regulation No. 66 [1]. These Rules [1] provide for the compliance of buses with passive safety at the design and manufacturing stage. However, during operation, the body of the bus wears out under the influence of corrosion and dynamic loads. Over time, there may come a time when the body of the bus will no longer meet the requirements for

passive safety [1]. It is almost impossible to determine the moment of inconsistency in operating conditions without the use of special methods and calculations. Carriers are more interested in profits rather than additional costs for checking the passive safety of buses on the one hand. On the other hand, operating organizations are interested in improving the corrosion resistance and durability of buses. In turn, reliable anti-corrosion protection of buses delays the moment of occurrence of a critical level of non-compliance with the level of passive safety. Today, there is a large selection of various polymeric materials, adhesive mixtures, and anticorrosive protection products,

even those that are not used in the automotive industry. These materials make it possible to positively influence the improvement of anticorrosive protection of buses since polymeric materials, unlike steel elements of the cladding, do not rust at all. The use of adhesive technologies instead of welding also reduces the total length of welds, which are also sites of corrosion evolution. Therefore, a relevant issue will always be the development of manufacturing technologies and improving the corrosion protection of bus bodies. The proposed materials must be experimentally checked for compliance with adhesion properties both at the beginning of operation and in the aging process. Improving technology and the use of advanced materials, taking into consideration actual operation, will increase the durability of buses. As a result, there will be a long-term compliance of buses with passive safety requirements in accordance with UNECE Rules No. 66 [1].

Thus, the research carried out should confirm the adhesion properties of the proposed materials. Namely, primers that are applied to the pipes of the body frame using adhesion improvement tools (primer, activator) and glued cladding materials (alucobond, zinc sheets). During operation, the proposed materials should not change their adhesion properties, so research is carried out using accelerated artificial aging technologies. When applying body cladding made of polymeric materials, the durability of the bus body can be limited only by the corrosion resistance of the body frame and the unchanging adhesion properties of adhesive mixtures. Therefore, to increase the durability of the body, in combination with the cladding of polymeric materials, it will also be important to protect the frame both from the outside and its closed cavities. With the use of cladding made of polymeric materials and highly effective protection of the body frame, restoration repairs will be significantly postponed, or even impracticable. After the end of the life cycle, the steel parts of the body will go for melting while the polymeric elements of the cladding will need to be recycled or disposed of. From the point of view of ecology, this causes some difficulties but will ensure the stability of proper passive safety of the bus. An alternative option to increase the corrosion resistance of the bus body may be the use of irrational and toxic cathaphoretic baths that require periodic disposal and are more harmful than polymer cladding.

2. Literature review and problem statement

In work [2], it is proved that corrosion of buses leads to their prolonged downtime. Given this, motor transport companies bear significant losses. This, in turn, complicates the normal operation of motor transport enterprises and adversely affects the quality of passenger transportation. Therefore, the development of bus body technologies in terms of corrosion and durability is of important practical importance. Work [3] reports the results of modeling the vibration load of the bus body, making it possible to assess the behavior of the body material in operation. However, the cited work does not take into consideration corrosion processes. Study [4] describes in detail how it is possible to predict the durability of the bus body, taking into consideration corrosion. In the continuation of work [4], it will be relevant to develop technologies for the manufacture of the body of the bus in terms of corrosion and durability. It is important that the model, which is presented in [4], makes it possible to predict the lifecycle of the bus. This will determine the onset of non-compliance with the requirements of UN Rules No. 66 [1] with any increase in

corrosion resistance of the body. To increase the corrosion resistance of the bus body, one can offer to make a stainless-steel body, or use individual body elements that are most affected by corrosion. The option using individual elements of the stainless-steel body is more rational but this will lead to an increase in the mass and cost of the bus, which contradicts modern trends in bus construction [5]. In work [5], they seek to reduce the mass of the body of the bus, which confirms the feasibility of using progressive lightweight polymeric materials. Progressive technologies also include the use of glued side panels, the type of alucobond (polymer sheets with a double-sided coating of aluminum film). Work [6] describes the use of body cladding elements with galvanic coating. The peculiarity of this corrosion protection is that cutting and forming body elements is carried out using a special technology. This technology [6] minimizes damage to the galvanic coating and provides for its protection in cutting sites. However, unlike [6], work [7] investigated intensive processes of corrosion products on zinc-coated steel sheets in aggressive environments. Therefore, when using steel sheets with double-sided galvanizing, they need to be covered with additional corrosion protection, which in combination will increase corrosion resistance. Paper [8] describes the use of cathaphoretic coatings and considers the shortcomings of such coatings and methods for increasing corrosion resistance. Cathaphoretic coatings undoubtedly have a high efficiency of corrosion protection. However, in the manufacture of bodies, cathaphoretic baths should be of large volumes. Accordingly, this requires additional equipment, the construction of a special workshop. With a relatively small batch of release, this method will not pay off. In addition, such corrosion treatment periodically requires constant renewal of the solution and its disposal. Therefore, unlike cathaphoresis [8], more rational methods should be used for anticorrosive protection of buses. Work [9] describes the operating conditions of public transport buses and proposed measures to increase the durability of bus bodies during operation. Paper [10] proposed technological principles to ensure the durability of bus bodies in the production process. Such methods [9, 10] require further development and introduction into production and real practice of operating organizations, in connection with more rational corrosion protection of bus bodies. Work [11] describes the harmful effects of atmospheric corrosion on metals. Taking into consideration this information [11], it is possible to develop methods to increase corrosion resistance of bus bodies using modern polymeric materials and highly effective finishing tools. Patents [12, 13] confirm the relevance of the use of cladding side panels made of plastic on passenger cars. Such panels are proposed to be used on special clips mounting [12], or gluing [13], which is more important for buses.

As a result of our review of literary data, it was found that there are many options for improving the corrosion resistance of bus bodies. However, existing technologies need to be improved, taking into consideration the possibility of using new polymeric materials and rational treatment methods, in terms of corrosion and durability of the bus.

3. The aim and objectives of the study

The purpose of this study is to improve the technology of the bus body in terms of corrosion and durability. This will make it possible to improve the corrosion resistance of bus bodies and increase their durability during operation.

To accomplish the aim, the following tasks have been set:

- to propose conceptual solutions for improving the technology of the bus body in terms of corrosion and durability, using automotive materials and progressive materials from another field of application, taking into consideration the specific purpose of the bus;
- to test adhesive mixtures with gluing surfaces regarding their adhesion properties, for further introduction into production, subject to the reliability and durability in the aging process.

4. The study materials and methods

The object of our research is the technology of bus bodies and the formation of recommendations for design bodywork subject to the regulated durability of the body introduced into production.

The main hypothesis of the study assumes that there are many modern polymeric materials that are not used in the automotive industry. When using such materials in combination with advanced technologies, corrosion resistance can significantly improve. In addition, new materials will increase the durability of bus bodies, subject to the verification of adhesion properties in the aging process.

Search methods were used to develop proposals and justify bus body technology in terms of corrosion and durability. At the same time, an analysis of anticorrosive treatment products, existing automotive materials, as well as other applications was carried out. Methods of gluing external panels of body cladding, including from non-automatic polymeric materials, and rational applications have been substantiated.

To test the materials for their adhesion properties for further introduction into production, methods of field experiment on the break machine P-5 in the laboratory were used in accordance with the ISO 4587 standard. For the maximum approximation of our laboratory tests to real operating conditions, a number of factors were taken into consideration: ambient temperature, high humidity, and salt fog. The first stage: the ambient temperature of the samples studied was maintained according to DIN 5014 for seven days at a value of 23 °C and 50 % humidity. The second stage: the samples were heated to a temperature of 80 °C for three days. The third stage: the samples were kept in water at a temperature of 70 °C for seven days. At the fourth stage, the samples were kept under the influence of salt fog for seven days according to ISO 11997-1:201. The samples, immediately before the tensile study, were aged at a temperature of 23 °C and 50 % humidity for two hours according to DIN 5014.

The error of representation is determined from the formula:

$$\Delta = \frac{\sigma}{\sqrt{n}}, \tag{1}$$

where n is the number of measurements; σ is the standard deviation;

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n-1}}, \tag{2}$$

where X_i is the i -th option; \bar{X} is the arithmetic mean;

$$\bar{X} = \frac{X_1 + X_2 + \dots + X_n}{n}. \tag{3}$$

Test samples consist of two strips of materials studied, glued together, overlapping each other. Fig. 1 shows the shape and size of the test samples used in the research.

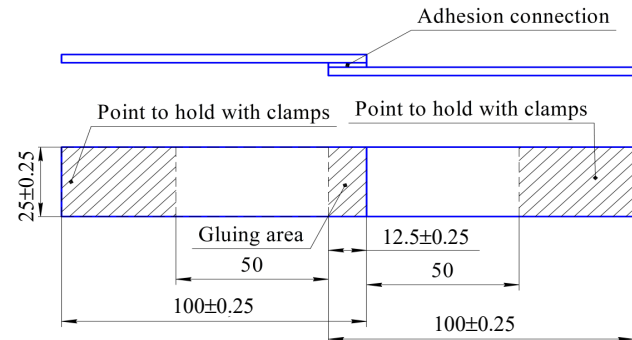


Fig. 1. The shape and size of the test samples used in the research

When preparing samples, the following requirements were taken into consideration:

- the samples were made of the same materials as the elements of the bus body;
- the displacement of the width when gluing two halves of the sample did not exceed 0.5 mm;
- the longitudinal axis of the glued sample has no curvature in the plane of the adhesive seam;
- parts of the extruded glue at the ends of the adhesive seam were cleaned before the test;
- 7 samples were taken for testing with each gluing technology;
- after gluing, the samples were aged for at least 12 hours before the test;

– the samples cut from pipes (cross-section, 40×60×2.5 mm) of the body frame are covered with the gray primer Helios 2K E-ZR, according to the technology of coating the body frame of the bus;

– the cut samples of steel sheets with double-sided galvanizing and polymer sheets of the Alucobond type (with double-sided aluminum coating) are not covered with primer.

Three options for application to glued surfaces of coatings are investigated, which, according to Sica technology, should improve adhesion:

- Sica Aktivator-100;
- Sica Aktivator-100 + Primer 206 G+P;
- Sica Aktivator-205.

For our research, four modifications of Sicaflex adhesives of black color were selected: Sicaflex-221, Sicaflex-252, Sicaflex-263, Sicaflex-265.

Since the strength on the cut of the studied Sicaflex adhesives according to CQP 046-1/ISO-4587 exceeds 5 MPa, the loads greater than 5 MPa must correspond to the cohesion break (about 160 kg of stretching at a break machine).

5. Results of studying the bus body technologies in terms of corrosion and durability

5.1. Conceptual solutions for improving the technology of the bus body in terms of corrosion and durability

After welding, the frame of the bus body does not have a protective coating (Fig. 2).

If one welds the cladding to such a body, and then carry out corrosion protection, as it was before, then there will be

a completely uncovered metal between the cladding and the body frame. As a result, from the first day of operation, the corrosion process will develop intensively. Such a bus will be operated until the body frame itself is destroyed under the influence of corrosion. Outside, such a bus will look quite decent. In addition, buses in these places that are welded (closed cavities) cannot be controlled during operation. In practice, there have been numerous cases when the body was removed from the frame and it simply fell apart. The consequences of such an imperfect design can be seen after 5–9 years of operation of the bus with the body of a bearing structure (Fig. 3). Very rarely, operating organizations, in order to close the uncovered metal, blew an anticorrosive agent (such as «Movil») under pressure in the gaps between the frame and cladding. This required removing all internal body cladding. At the same time, the bus was idle and all this required financial and labor costs. As a result, the service life increased slightly and these costs were not in vain. However still, the consequences of such an imperfect design can be seen after 5–9 years of operation of the bus with a body of a non-bearing structure (Fig. 3).



Fig. 2. Bus body frame after welding



Fig. 3. Destruction of the frame of the bus body under the influence of corrosion

Longer service lifespans apply to buses with additional coating and in cities with fewer residents.

Therefore, it was decided to develop such a technology for the manufacture of the body of the bus, which would provide for complete preliminary corrosion treatment of

the body. Given that a radically sharp transition from one technology to another is not carried out, the transition from outdated technology should take place in several stages. Moreover, it is important to see the results of the operation of buses with innovations, to conduct resource tests.

To this end, three possible options for improving the technology of manufacturing bus bodies have been conceptually proposed.

The first option provides for a preliminary coating of the body frame with high-adhesion anticorrosive primer according to ISO 12944-1:2017. In this case, the welding sites of the cladding are sealed with paint adhesive tape. Then, after the primer dries, the painting tape is unstuck, and the uncovered areas are covered with conductive primer. Figure 4 shows a body frame that is already covered with highly adhesion anticorrosive primer.



Fig. 4. The body frame of the bus, which is covered with high-adhesion anticorrosive primer

After drying of the conductive primer, two-sided galvanizing cladding is welded (Fig. 5). These buses use glued rear and front cladding masks to increase corrosion resistance and durability. The front and rear bumpers are also made of fiberglass. Unlike masks, bumpers are attached mechanically. Since the roof of the bus is subject to the least corrosion damage, the roof cladding of the bus is proposed to continue to be made of steel sheets without zinc coating. Steel sheets are welded. After a full cycle of welding and gluing of the front and rear masks, the body is transported to the shop of draft painting operations. There, the body is prepared, covered with anticorrosive primer of the Helios brand. Body elements directed to the roadway are covered with a special anticorrosive mastic of the Dinitrol brand.

Next, according to the developed technology, the closed cavities of the bus pipe frame are treated with a preservative of closed cavities of the Dinitrol brand. According to the old technologies, closed cavities were not treated at all, in extreme cases only thresholds were protected. The treatment of closed cavities relied on operating organizations, which largely ignored the implementation of additional corrosion protection. In addition, technological holes in the body for the supply of anticorrosive liquid were not provided. Therefore, that further complicated anticorrosive treatment. With haphazard drilling of holes in places not provided by the manufacturer, there was inevitably an additional weakening of the body.



Fig. 5. The body frame of the bus, which has welded cladding with double-sided galvanizing

As a result of the analysis of restoration repairs of bus bodies, it was established that the body frame is subject to intensive corrosion processes only below the windowsill beam. Moreover, the frame of the front part of the body is securely protected by a front mask and bumper. In addition, the front of the bus is better ventilated and dried from the heated engine. Therefore, the treatment of closed cavities is proposed as follows. Treatment, first of all, must be applied to the base frame by 100 %, since corrosion destruction of the base frame leads to the impossibility of further operation of the bus (Fig. 6).

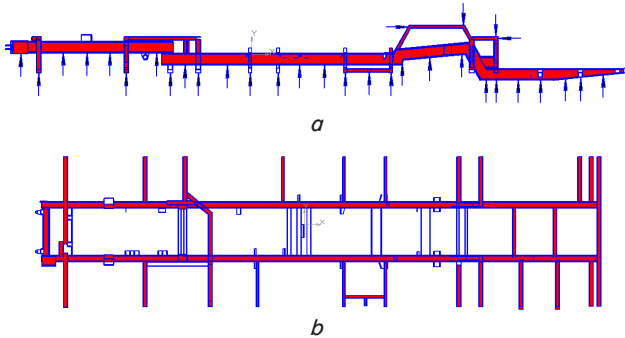


Fig. 6. The scheme of treating the frame of the base of the bus body: *a* – side view; *b* – top view

In the places of supply of anticorrosive liquid, technological holes with a diameter of 10 mm are drilled, in which Dinitrol substance is supplied under a pressure of 10–15 kgf/cm². For normal penetration of anticorrosive fluid, the temperature in the room of the paint shop should not fall below 20 °C. Then, after the excess anticorrosive liquid leaks from the technological holes, they are closed with special plugs.

The frame of the back of the body corrodes under the rear bumper since dirt and moisture accumulate in this place. In winter, when the roadway is sprinkled with salt-sand mixtures against icing, an aggressive environment for intensive corrosion development is formed under the rear bumper. Therefore, the bottom of the frame of the back of the body requires external treatment with mastic, and the inner cavities with Dinitrol anticorrosive liquid. Fig. 7 shows the scheme of application of anticorrosive fluid in the closed cavities of the frame of the back of the body.

As the experience of operating organizations shows, the body frame, when using outdated technology, intensively

corrodes below the windowsill beam. Taking into consideration the fact that according to the new technology, the body frame is proposed to be first treated with primer, and then welded cladding, the corrosion intensity should significantly decrease below the windowsill beam. Therefore, it is proposed to treat closed cavities below the windowsill of the following elements: thresholds and the frame of wheel arches. All other pipes at the level of luggage and auxiliary compartments are also subject to treating: air filter compartment, fuel tank compartment, autonomous heater compartment, battery compartment. In addition, in the open compartments, frame pipes are externally covered with anticorrosive mastic. Fig. 8 shows the scheme of treating the frames of both sides of the bus.

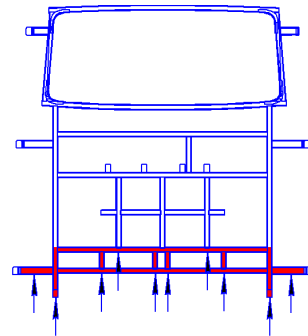


Fig. 7. The scheme of treating the frame of the back of the bus body

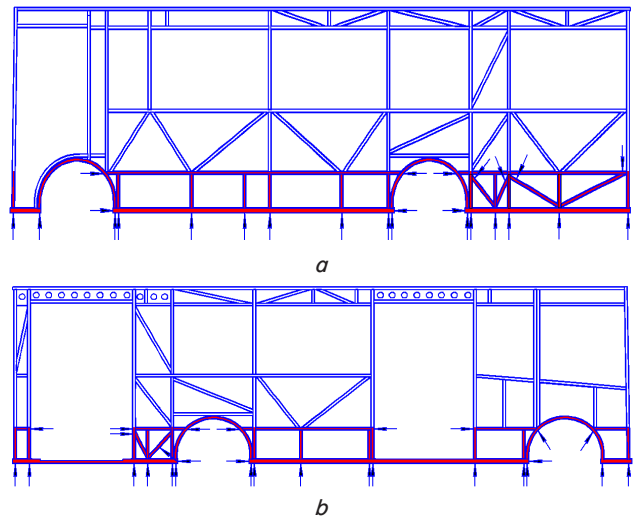


Fig. 8. The scheme of treating the frames of the right and left sidewalls of the bus body: *a* – the frame of the left sidewall; *b* – the frame of the right sidewall

After treating in the shop of rough painting operations, the bus is sent to workshop of pure painting operations. There, the bus is prepared for painting (putty if necessary), covered with finishing primer. After drying, the primer is covered with Helios paint and varnish. Varnish coating increases the cost of the bus, so the type of coating should be discussed with the consumer. This body manufacturing technology involves the installation of glasses in rubber seals with fixation around the perimeter with a classic round section lock.

In the second version, the developed body production technology is more advanced and will have a number of differences from the previous one. Firstly, the body frame

after welding will be completely covered with high-adhesion anticorrosive primer, with the exception of welding sites for roof coverings. In the places of welding roof edging, the body frame is covered with conductive primer. Side panels are made of sheets with double-sided zinc coating. It is proposed to form edges around the perimeter of metal sheets for gluing and increasing rigidity. It is proposed to glue these panels with the help of universal adhesive mixtures Sicaflex, which have not yet become widely used in the automotive industry. To increase adhesion, the body frame, and the cladding of the side panels in the gluing areas are pre-coated with the Primer liquid, which improves adhesion properties. Thus, this body manufacturing technology involves gluing all the cladding panels (plastic – front and rear masks, with double-sided galvanizing – side panels), except for roof cladding. Roof cladding is made of steel rolled steel without galvanizing. Figure 9 depicts the body of the bus, which is made according to the second version of the technology.



Fig. 9. The body of the bus with glued side panels with double-sided zinc coating

This technology involves gluing all fixed glasses: wind, rear, and side. Movable glasses are mounted in the frames, which are then also pasted into the holes. To ensure proper adhesion, each glass at the gluing point is covered with an activator and primer, the corresponding body panels are covered with a primer, and only then Sicaflex glue is applied. Glued parts are securely fixed until the glue dries completely in compliance with gaps around the perimeter. To prevent skews of the rib, which will lead to cracks in the glasses themselves, control of the draft with special templates is carried out. After assembly, each bus must pass the sprinkler chamber to check the body for tightness. In the case of detection of leaks, the non-hermetic element is cut and glued in compliance with all stages of the technology. To cut the glasses, so as not to damage them, a steel string is used. After the body is checked for tightness, the sealant is pushed between the glued glasses. The cutting is carried out to eliminate the moisture of dirt and dust, as well as to reduce the vibrations of the glasses. In addition, the presence of that prevents the penetration of water and its freezing, which can lead to the unstuck glasses. Pasted glass, unlike inserted rubber seals, additionally increase the rigidity of the body, which contributes to ensuring proper leveling of body strength.

The third version of the technology includes the most modern elements of body manufacturing structures using the

maximum number of polymeric materials. This increases the corrosion resistance of the bus body and reduces its mass. This technology differs from the previous one in that the side panels of the body cladding are made of polymer sheets with a double-sided coating of aluminum film (the type of Alucobond). Such sheets are glued according to the technology of the second option (Fig. 10).



Fig. 10. The body of the bus, the side panels of which are sheathed with polymer sheets with a double-sided coating of aluminum film (the type of Alucobond)

Polymer sheets with double-sided coating of aluminum film are proposed for the manufacture of cladding bus bodies.

In this version of the technology of manufacturing the body of the bus (Fig. 10), the front and rear masks are made of fiberglass panels.

Thus, the maximum use of polymeric materials in the manufacture of the cladding of the bus body frame improves its corrosion resistance and reduces the mass. Modern computer technologies make it possible to make calculations on the strength of bus bodies using polymeric materials. What is important when calculating the body of the bus is to ensure its equal strength. One of the underexplored components when gluing the cladding of buses were adhesive mixtures. It was not known how the glued panels of the bus body cladding would be put into operation. Therefore, it was decided to conduct laboratory tests of glued samples of cladding to the elements of the body frame, taking into consideration the aging process.

5. 2. Results of testing the materials of the cladding of the bus body regarding their adhesion properties

Since gluing mixtures and fiberglass cladding that were not previously used in the automotive industry were proposed for gluing the cladding, experimental studies of the adhesion properties of the proposed glued joints according to ISO 4587 were conducted. To create conditions that correspond to actual operation, the aging of samples was carried out in accordance with the standard CQP-034 [14] in combination with ISO 11997-1:2017.

After conducting a series of tests, our results confirm the use of the gluing of side panels with a cohesion break of more than 95 %. With a value of less than 95 %, options are not allowed for use in practice. To assess the conformity of proper adhesion from each batch, the lowest value of the cohesion break was selected. Table 1 gives the results of testing samples from each batch.

As the results of our test show (Table 1), the use of the best adhesive mixtures Sicaflex provides a cohesion break exceeding 95 %. This has made it possible to introduce the universal adhesive mixtures Sicaflex, which had not previously been used for this purpose, into real production.

Table 1

Results of testing the adhesion properties of samples

Glue brand	Brand of means of treating before gluing		
	Sica Aktivator-100	Sica Aktivator-100+Primer 206 G+P	Sica Aktivator-205
Sicaflex-221 black	Cohesion break 97.42 ± 1.71 %	Cohesion break. 76.86 ± 1.34 % (10 % exfoliation of the primer after storage in water)	–
Sicaflex-252 black	Cohesion break 96.42 ± 1.71 %	Cohesion break 97.00 ± 1.70 %	–
Sicaflex-252 AT white	–	–	Cohesion break 96.43 ± 1.69 %
Sicaflex-252 AT black	–	–	Cohesion break 74.44 ± 1.31 %
Sicaflex-263	Cohesion break 96.57 ± 1.73 %	Cohesion break 97.00 ± 1.70 %	–
Sicaflex-265	Cohesion break 97.14 ± 1.70 %	Cohesion break. 97.14 ± 1.70 %	–

6. Discussion of results on improving the technology of the bus body in terms of corrosion and durability

As a result of improving the technologies of the bus body in terms of corrosion and durability, new promising technologies for the production of bodies using modern polymeric means have been obtained. Materials that have not been previously used in the automotive industry have been proposed. According to existing technologies, the body was not covered with primer at all before welding the elements of the cladding (Fig. 2). According to the new technology, a full coating of the body frame with high-adhesion anticorrosive primer (Fig. 4) ensures an increase in the durability of the bus body. This technology was introduced on buses of the «Ataman» brand, manufactured at AT «Cherkasy bus» (Ukraine). Unlike previous modifications, on these buses «Ataman» A092N6, the closed cavities are treated according to schemes in Fig. 6–8, through technological holes. The use of technological holes based on design documentation under factory conditions prevents weakening of the body in the case of self-drilling of holes in their absence. Side cladding from steel sheets with double-sided galvanizing is glued (Fig. 9) and all fixed glass windows are glued.

Buses «Ataman» A092N6 with the advanced technology of corrosion protection began operation in Kyiv in 2016 (service life, 6 years). In these buses, the body frame is in satisfactory condition and does not require restoration repairs. Buses of previous years of production, during operation in cities with more than 1 million inhabitants, after 5 years began to undergo restoration repairs (Fig. 3). Further operation will show how many times the durability of the body with improved technology will increase.

The new Ataman D093S2/S4 school buses use simplified technology, which also introduces some advanced technical solutions. Side steel panels with double-sided galvanizing (Fig. 5) are welded to a body previously covered with high-adhesion anticorrosive primer. Moreover, in the welding sites, conductive primer is applied. Closed cavities are treated in the same way as that proposed in schemes in Fig. 6–8. Such buses have been in operation since 2015 in all regions of Ukraine. The condition of the bodies of school buses «Ataman» D093S2/S4 is somewhat better than the A092N6. This is due to the fact that the city buses A092N6 carry passengers with periodic overloads (during rush hour) with an average annual run of 70–100 thousand km. The annual run of school buses does not exceed 20 thousand km. Thus, as real operation shows, it is im-

practical for school buses to further improve the technology of the bus body in terms of corrosion and durability. Such improvements will lead primarily to an increase in the cost of the bus.

Unlike school buses, city buses need further improvements in manufacturing and corrosion protection technologies. In particular, in Germany, requirements are established to increase the service life of buses to 20 years. Therefore, at enterprise VAT «Ukravtobusprom» (Lviv, Ukraine), the best of the proposed bus body technologies in terms of corrosion and durability (the third option) was introduced into production. The main difference from the production technology of the body «Ataman» A092N6 is the use of side panels with polymer sheets (the type of Alucobond), which were first introduced into the automotive industry. The use of Alucobond sheets in comparison with steel sheets is twice as expensive but the resource of polymeric sheets is longer by 10 times. One of these projects was developed to transport passengers in German cities. In addition, the durability of the body is up to 20 years, when developed at VAT «Ukravtobusprom», ensures compliance with the conditions of equality of the body frame using modern application design programs. The reliability and durability of new materials that have not been used in the automotive industry before being introduced into production is necessarily confirmed by field tests. Before the introduction into production, a study was conducted on the adhesion properties of adhesive mixtures, which should not lose their properties during aging. Table 1 gives the results of tests that make it possible to choose the best materials for use in production. During the tests, it was found that most of the samples showed a cohesion break exceeding 95 %. This means that when applying an effort that exceeds the strength of the glue on breaking, 95 % of the rupture occurred along the glue itself. Such results of laboratory tests suggest that the proposed gluing mixtures can be used in the automotive industry since they will ensure reliable gluing of the bus cladding panels.

Thus, our solutions can improve the corrosion resistance of bus bodies in accordance with specific operating conditions. Firstly, the use of side composite panels that are glued makes it possible to reduce the total length of welds by 2.5–3 times, which are local sites of corrosion. Secondly, the full coating of the body frame with anticorrosive primer before welding or gluing the cladding makes it possible to provide continuous protection of the frame from corrosion. Thirdly, the rational treatment of closed cavities further increases the corrosion resistance of the body frame.

The use of obtained, equivalent to corrosion protection, solutions makes it possible to abandon the use of cathodic baths. Refueling one bath is about USD 40 thousand. In addition to the high cost of refueling the bath, it has a number of restrictions and problems with waste disposal. The number of immersions in the bath and the service life of the cathodic solution are limited. Such a bath will work effectively only with the production of at least 3,000 buses per year (in real production, no more than 400 units per year). Despite the increase in the technology of corrosion protection, in comparison with the old technology, the developed technology is much cheaper and more efficient than cathodic coatings.

The use of front and rear masks made of fiberglass makes it possible under the conditions of production to quickly reconfigure production in accordance with the new design solutions of the bus body (Fig. 10). Side panels made of Alucobond material have an ideal flat surface for painting. Between the glued side panels, to compensate for temperature and mechanical deformations, gaps of 5–10 mm are provided. To preserve the proper aesthetic appearance, these gaps are filled with sealant for pasting. In addition to the proper aesthetic appearance, sheets of Alucobond material in combination with sealed pasting provide a decrease in noise effects during the operation of the bus.

When applying the proposed technologies in practice, the body life of a bus with polymer panels of the Alucobond type will be at least 20 years. The durability of polymeric sheets of the Alucobond type is confirmed by their long-term operation as the cladding of multi-story frame houses with a service life of more than 30 years. Such materials are specially designed for use at wide temperature intervals and under the influence of ultraviolet radiation. A more detailed forecast can be made in further studies using simulation modeling, the methodology, and results of which are given in [4]. Work [4] substantiates the influence of sand and salt mixtures on the body of the bus. Factory protection of closed cavities is also taken into consideration, without updating which the corrosion process is intensified after 2 years of operation of the bus.

A set of polymeric sheets of the Alucobond type, in comparison with zinc sheets, is 2 times more expensive. However, when using glued side panels, the length of welds decreases by 2.5 times. Reducing the total length of welds leads to savings in some items of expenditure. A 2.5-time saving of materials for welding are ensured: welding wire and carbon dioxide. 2.5 less is electricity consumption for welding and reduced wages of welders. According to the planning and financial department of AT «Cherkasy bus», the use of new technology using polymer composite materials leads to an increase in the cost of manufacturing the bus by about USD 1,200. However, the durability of such a body will be at least 2 times greater, which compensates for the further costs after 9 years for restoration repairs. The minimum cost of restoration of the body is about USD 3,500, which extends the total life of the bus by only 1.5 times.

When introducing into production, restrictions on the use of the presented technologies should also be taken into consideration. Such technologies can only be used on buses, the bodies of which are made of rectangular steel pipes. Pasting the side of the body frame with polymer sheets of the Alucobond type should be carried out only on flat side surfaces (without deformations of sheets). To curved areas of the body frame should be welded or glued sheets with

double-sided galvanizing, when forming the appropriate profile of sheets.

The disadvantages of the study include the increased cost of implementing the proposed technologies at the stage of manufacturing the body of the bus, in comparison with basic technologies. Accordingly, such solutions will lead to an increase in the cost of the bus.

The development of this study may involve assessing the impact of other polymeric materials on the corrosion resistance of bus bodies in order to reduce the cost of technological solutions. Moreover, cheaper technologies should not lead to a deterioration in corrosion resistance.

7. Conclusions

1. Conceptually, three possible options for improving the technology of manufacturing bus bodies in terms of corrosion and durability, using modern progressive materials, have been proposed. Most of the materials offered have not been used in the automotive industry before. All three options provide for preliminary coating of the body frame with the high-adhesion anticorrosive primer Helios 2K E-ZR, thickness of 65–80 μm , before gluing or welding the cladding. At the first option, side panels with a double-sided zinc coating are welded, and in welding areas the body frame is covered with the Korro PVB conductive primer with a thickness of 20 μm . This option will ensure the rational durability of school buses. The second option is more advanced and effectively protect the body of the city bus from corrosion. Unlike the first, side panels are already glued with Sicaflex glue – 265 with the previous application of the Sica Aktivator-100, as well as all fixed window glass are glued. The third option will ensure the greatest durability of the bus body (up to 20 years) since the side panels of polymeric material Alucobond are glued. The transition to new adhesive technologies of body cladding from composite corrosion-resistant materials instead of steel sheet, makes it possible to reduce by 2.5–3 times the total length of welds. Reducing the number of welds reduces the number of local bases for corrosion and deterioration of physical and mechanical characteristics of the body structure. This solution further increases the corrosion resistance of the bus body.

2. We tested adhesive mixtures with gluing surfaces regarding their adhesion properties, for further introduction into production, under the conditions of reliability and durability in the aging process. Based on the results of research, the Sicaflex adhesive mixtures for gluing cladding in combination with the Helios primers were introduced into production when covering steel pipes of the bus body frame. Before testing the samples for rupture, it was a prerequisite to age the samples in accordance with the CQP-034 standard in combination with ISO 11997-1:2017, reflecting the conditions for the actual operation of buses. The best results (cohesion break, exceeding 95 %) were demonstrated by the following adhesives: Sicaflex-252, Sicaflex-263, Sicaflex-265 when previously applied to the surface of gluing Sica Aktivator-100. It is established that before applying the glue, it is not necessary to cover the materials with Primer (a substance that should still improve adhesion and increase the cost of technology). The additional application of the Primer 206 G+P leads to 10 % exfoliation of the primer after storage in water and a reduction in the cohesion break to 75 %.

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