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Corrosion Activity of Carbon Plastics and Protection of Metal Power Structures in Contact with Carbon Plastics

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Abstract—Methods for assessing the corrosion activity of carbon plastics against metal materials and development of complex anticorrosive protection of load-bearing units of structures including carbon plastics in contact with metal materials are considered. Data on the electrochemically measured corrosion rates in carbon plastic–metal contact pairs and on the efficiency of separating layers (sealants, glass fabrics) are presented. Recommendations on corrosion protection of carbon plastic–metal joints are given.

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All major world's producers include in the design of new-generation aircrafts more and more composite materials, including carbon plastics. In many cases the use of carbon plastics is the only possible way to decrease the weight of a construction without sacrificing flight characteristics.

As known, in assemblies comprising carbon plastics and metal materials, the former serve as a cathode which is much more active than copper and copper alloys. Direct corrosion tests and research on the electrochemical properties of metal materials in contact with carbon plastics showed that the most vulnerable in such assembled structures are magnesium and aluminum alloys, as well as zinc- and cadmium-plated steels.

Evidence for our research results comes from foreign publications. According to the US Air and Naval Forces, the highest threat of corrosion arises after drilling holes for fastening details in graphite epoxy panels. Drilling exposes ends of graphite fibers which contact with fastening details and plugs. Research at the U.S. Army Aviation Material Laboratories on combinations of structural alloys with graphite epoxy composites, allowed these materials to be divided into three groups: acceptable, critical, and inacceptable (Table 1). The assessment was performed in terms of the current density across the contact pair.

In view of the enhanced corrosion activity of carbon plastics to the most part of metal materials, assembly units including carbon plastics require special approaches to their design and corrosion protection. Carbon plastic–metal assembly units are subject to special requirements to constructive adaptation to corrosion protection, according to State Standard 24627 and Tentative Standard 1.90368.

Test Methods

Corrosion tests on carbon plastics combined with various metal materials and tests on the efficiency of anticorrosion agents for metal–carbon plastic couples were performed by the following methods.

Electrochemical characteristics were measured in a 3% solution of sodium chloride on an IPC-Pro potentiostat. Steady-state potentials (E_{st}) after exposure of samples in a working solution for 24 h with a normal hydrogen reference electrode; anodic polarization curves for D16T and 1420TG1 alloys and cathodic curves for VT-23, 30KhGSA, Brazh-5, and KMU-4 alloys were measured. The current through a couple of materials in contact was determined by comparing the anodic and cathodic polarization curves.

The corrosion activity of carbon plastics with respect to metal materials in a corrosion-active

Table 1. Acceptable combinations of structural metal materials and graphite epoxy composite materials

Material	Acceptability of combination, galvanic couple current density, mA cm^{-2}
Ti-6Al-4V	Acceptable $I < 5$
Ti-6Al-2Sn-4Zr-2Mo	
Rene-41 (Ni-19Cr-11Co-10-Mo-3Ti-1.5Al)	
Inkonel X (Ni-15Cr-7Fe-2.5Ti-1.0Co-0.7Al)	
Inkonel (Ni-15Cr-7Fe)	
AFC-77 (Fe-14.5Cr-13Co-5Mo-0.4V-0.15C)	
PH17-7 (Fe-17Cr-7Ni-1.2Al-0.07C)	
Corrosion-resistant steels 301 and 304	
Cu-1Be	
Aluminum graphite fibers (alloy 6061, 30% of fibers)	Critical $5 < I < 15$
MA -87 (powder alloy) (Al-6.5Zn-2.5Mg-1.5Cu-0.4Co)	
Aluminum alloys 2024-T3, 2024- T6, 7075-T6	
Corrosion-resistant steel 440 C	
Steels 1020 and 4130	
Steel 300M (Fe-5Mo-1.85Ni-1.6Si-0.9Cr-0.85Mn-0.42C)	Inacceptable $I > 15$
Steel 10Ni (Fe-14Co-10Ni-2Cr-1Mo-0.14C)	
Steel 4340	
Aluminum alloy 2020-T651	

medium was determined according to State Standard 9.902. The procedure involves 8 cyclic tests by the following program: heating to 60°C for 12 h and subsequent exposure in a climatic chamber at a relative humidity of 98% for 6.5 days.

The corrosion activity of carbon plastics on the basis of domestic and foreign carbon fabrics with respect to the following typical materials: the aluminum alloys D-16T and D-16AT, without coating and with a chromate anodic oxide coating (CAOC), polished 30KhGSA steel, chromate-passivated cadmium-plated steel (thickness 9 μm), etched titanium alloy OT-4-1, and passivated Kh18N9T steel. The tests samples were plates with the dimensions 80×30×δ mm. The number of each metal samples was no less than 5, and the number of each nonmetal samples was no less than 3. Of the five metal samples, three contacted with carbon plastic and two served as reference.

Before bringing in contact with carbon plastic, metal samples were surface-degreased with gasoline or ethanol and kept in a dessicator for 24 h. Chemical and galvanic coatings were applied and steel samples were passivated, following current sectorial standards. The contact of metal samples with carbon plastic was provided by means of clamps with uniform tightening over the entire sample surface.

The following parameters of carbon plastic samples were measured: pH of the aqueous extract; contents of corrosion-active substances in the aqueous extract (Cl^-, SO_4^{2-}). According to State Standard 9.902, a material is corrosion-aggressive when the Cl^- and SO_4^{2-} contents in the aqueous extract are above 0.02 and 0.05%, respectively, and the pH of the aqueous extract is below 6.0 or above 8.5.

Structural samples of rivet joints were tested in a salt mist chamber (SMC) for 6 months. The samples were overlap joints of KMU-3L carbon plastic with D16AT aluminum alloy, OT-4 titanium alloy, and KMU-4L carbon plastic. The rivets were made of V65 aluminum alloy and VT-30 and VT-16 titanium alloys.

Simultaneously, the structural components of bolt assemblies made of different materials were subjected to corrosion fatigue tests. The procedure involved alternating fatigue loads and exposures in a corrosive medium in the SMC under a constantly sprayed 5% NaCl solution and 35°C. After two testing cycles, assessment of the corrosion-induced reduction of fatigue strength was performed.

The samples represented two carbon plastic plates butt-jointed by means of aluminum alloy cover plates joined with titanium alloy fasteners. The samples were fabricated of two alloys (1163T and V-14690 and a Porcher carbon fabric-based plastic as the most active in contact with aluminum alloys; as fasteners we chose VT6 titanium alloy bolts with an anodic oxide coating and a cadmium-plated 30KhGSA carbonized steel.

In choosing corrosion protection means for metal materials in contact with carbon plastics we based on the requirements to metal and nonmetal materials and anticorrosion protection (Tenative Standard 1 90368-86) for flight vehicles operated in any weather conditions. Customer's requirements, results of long-standing research, and experience in exploitation of planes and helicopters were also taken into account. As a result, the following protective coatings were chosen.

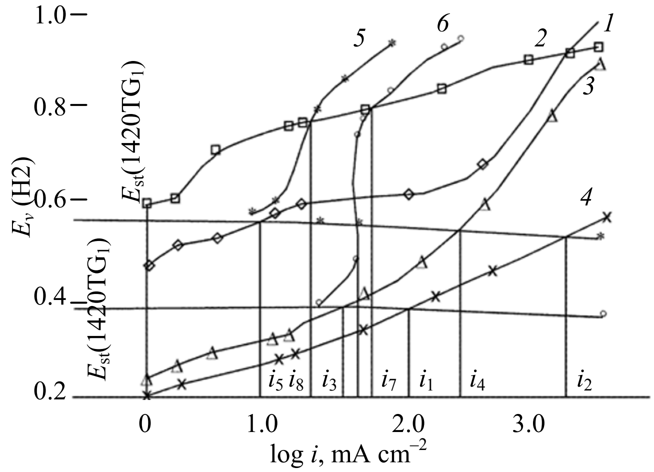

Fig. 1. Polarization curves in a 3% NaCl solution: cathodic: (*1*) VT-23, (*2*) ZOKhGSA, (*3*) Brazh-5, and (*4*) KMU-4; and anodic: (*5*) 1420TG1 and (*6*) D16T.

As the protective nonmetal inorganic coatings for aluminum alloys we chose a commercial anodic oxide coating treated in a potassium dichromate solution, for 30KhGS steel fastener, a galvanic cadmium coating, and for a VT-6 titanium alloy fastener, an anodic oxide coating.

Table 2. Corrosion activity of carbon plastics with respect to metal materials

Brand of carbon plastic	pH of aqueous extract	Ion contents, wt %		Corrosion resistance of contacting metal materials after cyclic tests
		Cl^-	SO_4^{2-}	
KMU-4-2M-3692 (ENFB-2M-R-3692-3K-NTA)	3.50	Not detected	Not detected	Strong corrosion enhancement (by 50%) of alloys D16T and D16AT, steel 30KhGSA without plating and with cadmium plating (45%). Corrosion of steel Kh18N9T and alloy VT6 is lacking.
KMU-7-2M-3692 (VS-2526K-R-3692-3K-NTA)	4.70	0.019	0.010	Strong corrosion enhancement (by 50%) of alloys D16T and D16AT, steel 30KhGSA without plating and with cadmium plating (45%). Corrosion of steel Kh18N9T and alloy VT6 is lacking.
KMU-11-M-3692 (EDT-69(M)-R-3692-3K-NTA)	6.36	0.017	Not detected	Corrosion enhancement (by 30%) of alloys D16T and D16AT, steel 30KhGSA without plating and with cadmium plating (30 %). Corrosion of steel Kh18N9T and alloy VT6 is lacking.
Cytec (985/T-300) carbon plastic	6.21	0.005	Not detected	Corrosion enhancement (by 20%) of alloys D16T and D16AT, steel 30KhGSA without plating and with cadmium plating (15 %). Corrosion of steel Kh18N9T and alloy VT6 is lacking.
Hexcel (8552/AS-4-12K) carbon plastic	6.28	0.006	Not detected	Corrosion enhancement (by 20%) of alloys D16T and D16AT, steel 30KhGSA without plating and with cadmium plating (15 %). Corrosion of steel Kh18N9T and alloy VT6 is lacking.

Table 3. Results of corrosion tests of welded joints of KMU-3l carbon plastic with metals

Material in contact with KMU-3l	Fastener material	State of samples after corrosion tests, 180 days	
		Tropical climate chamber	SMC
D16AT	VT-30	Strong corrosion of D16 in sites of contact with carbon plastic, welding joints are intact (Fig. 2a)	Strong corrosion in sites of contact, welding joints are intact (Fig. 3a)
KMU-4l	V65 (CAOC) Steel 20 washers	Corrosion products around welding joint heads, corrosion of steel washers (Fig. 2b)	Strong corrosion of welding joints and steel washers (Fig. 3b)
OT-4	V65 (CAOC)	Corrosion products around welding joint heads in sites of contact with carbon plastic and OT-4 (Fig. 2c)	Strong corrosion of welding joints.

Additional corrosion resistance was provided by means of a lacquer paint coating (LPC): hot-dried EP-0215 primer, 1 layer of a cold-dried VG-28 primer, and 2 layers of Aerodur C21/100UVR enamel; for carbon plastics : cold-dried EP-0104 primer and 2 layers of EP-140 enamel.

Additional protection of metal–carbon plastic couples from contact corrosion was provided by means of U30MES-5 and VGM-9 sealant, T64 and T10 glass fabric, and nickel foil gaskets. Fasteners were mounted using VP-1 paste on the basis of a rubber–epoxide oligomer containing corrosion inhibitors.

The efficiency of protective coatings (nonmetal inorganic, metal, sealants) and isolating layers on aluminum alloys in contact with carbon plastics on soaking in a 3% NaCl solution was studied electrochemically using an IPC-Pro potentiostat, according to Methodical Materials 1.595-7-167-2003. Anodic and cathodic polarization curves were measured. The aluminum alloy 1163 was tested with no protective coatings and with an anodic oxide coating; 30KhGSA steel with no coating and with a cadmium coating; as the gasket layers we studied U30MES-5M sealants, T10 and T64 glass fabrics, as well as a 30-μm nickel foil (by 3 samples each combination) were tested.

Results of Assessment of Corrosion Activity of Carbon Plastics

The aluminum alloy 1420TG1 in contact with KMU-4 carbon plastic has a 2.5 order-of-magnitude higher than in contact with a titanium alloy and an order-of-magnitude higher than in contact with Brazh-5 (Fig. 1). Comparison of the anodic polarization curves of aluminum alloys in their intersection points with the KMU-4 cathodic curve shows that the corrosion current of 1420TG1 alloy in contact with carbon plastics is much higher than that of D16T alloy in contact with carbon plastics.

Table 2 lists the test results for carbon plastics on the basis of domestic and foreign fabrics.

Tests on Structurally Similar Metal–Carbon Plastic Samples

Tables 3 and 4 show the results of corrosion tests in salt mist and tropic chambers for 180 days for welded

(a) (b) (c)

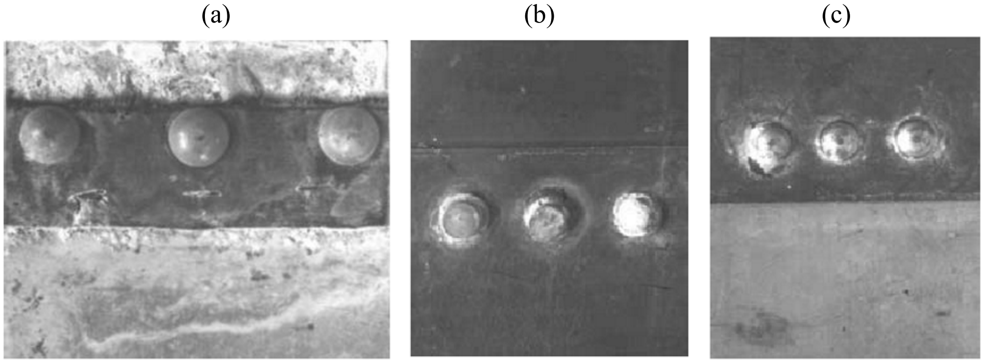

Fig. 2. Samples after corrosion tests in a tropical climate chamber: (a) D16AT (CAOC), KMU-3l, VT-30 welded joints; (b) KMU-3l, KMU-4l, V65 welded joints (CAOC); and (c) KMU-3l, OT4, V65 welded joints (CAOC). Test time 6 months.

(a) (b)

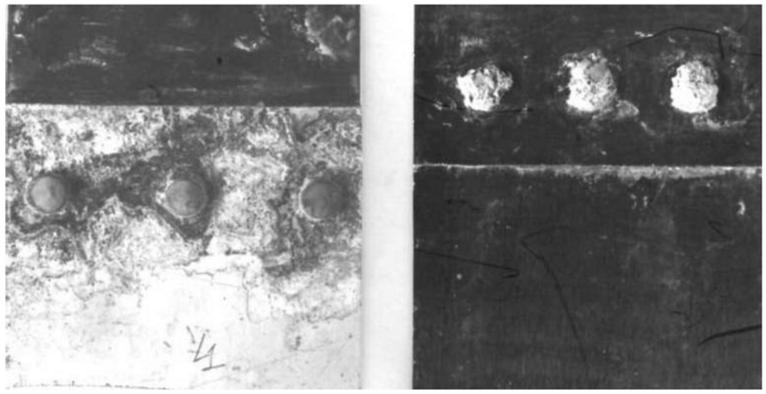

Fig. 3. Samples after corrosion tests in a salt mist chamber: (a) D16AT (CAOC), KMU-3l, VT-30 welded joints and (b) KMU-3l, KMU-4l, V65 welded joints (CAOC). Test time 6 months.

Table 4. Corrosion tests in SMC of welding joints of KMU-3l carbon plastic with metals

Material in contact with KMU-3l	Fastener material	State of surface after tests in SMC, 180 days
KMU-4l	V65 (CAOC) welding joints, D16 washers	Corrosion in sites of contact of welding joints and washers with carbon plastic. LPC is intact (Fig. 4a)
KMU-4l	VT-16 welding joints and washers	Welding joints and LPC are intact (Fig. 4b)
D16AT (CAOC)	V65 (CAOC) welding joints, Steel 20 washers	Strong corrosion of D16 with LPC swelling (Fig.4c). Fine Fine blisters on the LPC over the carbon plastic surface. Strong corrosion of V65 fastening; VT-16 fastening is intact (Fig. 4d)
D16AT (CAOC)	VT-16 welding joints	
D16AT (COC)	VT-16 welding joints	Strong corrosion of D16 with LPC swelling (Fig. 4e)

Table 5. Results of repeated tension tests of joints between carbon plastic and aluminum alloys. Four-rowed double-shear bolt (d 6 mm) joints: σ^{netto} = 196 MPa, R = 0.1, f 5 Hz

Separating layers	Starting endurance, kc	Load, kc			Total endurance (N_1+N_2+ N_{res}), kc (averaged over 3 samples)
		N_1	N_2	N_{res}	
1163T Alloy–carbon plastic on the basis of Porcher fabric					
Ni foil, 30 μm	298.0	60	55	–	115
VGM-9 sealant	171.0	60	60	10	130
U30MES-5 sealant	171.0	60	60	30	150
T64 glass fabric	197.8	60	60	117	237
T10 glass fabric	197.8	60	60	170	290
V-1469 Alloy–carbon plastic on the basis of Porcher fabric					
Ni foil, 30 μm	241.0	60	41	–	101
VGM-9 sealant	173.0	60	53	–	113
U30MES-5 sealant	173.0	60	60	10	130
T64 glass fabric	191.0	60	60	41	161
T10 glass fabric	191.0	60	60	70	190

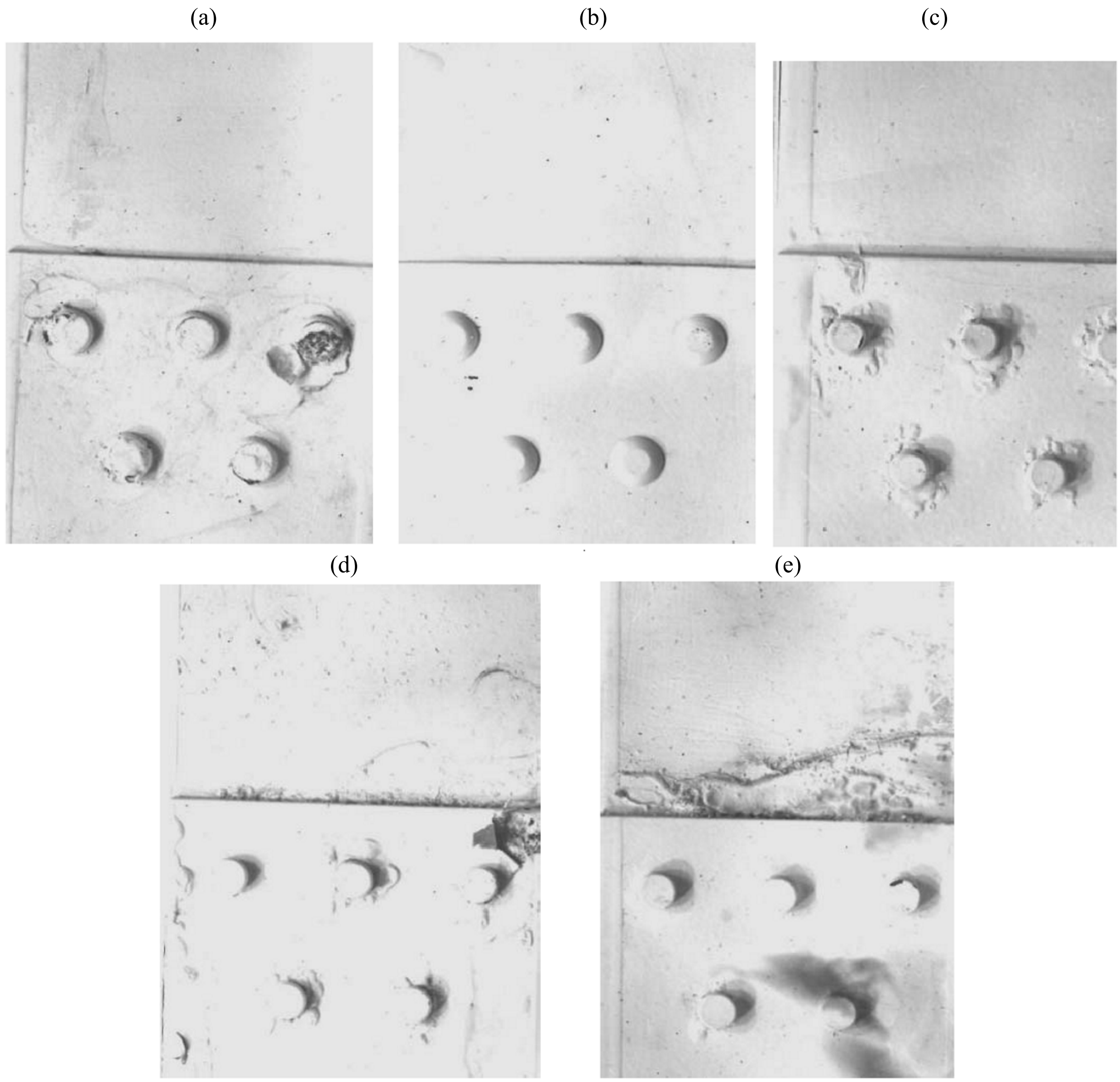

Fig. 4. Images of LPC-protected samples after corrosion tests in a salt mist chamber: (a) KMU-3l, KMU-4l, V65 welded joints (CAOC); (b) KMU-3l, KMU-4l, VT-16 welded joints; (c) KMU-3l, D16AT, V65 welded joints (CAOC); (d) KMU-3l, D16At, VT-16 welded joints; and (e) KMU-3l, D16AT (chemical oxide coating, COC), VT-16 welded joints. Test time 6 months.

joints of KMU-3l carbon plastic with metal materials. The metals were protected with lacquer paint coating (LPC) systems: setting rivets on AK070 primer and EP-0104+FP-5105+KCh-5185 primer on the surface. The design of the samples is shown in Figs. 2 and 3. Express corrosion tests of the welded joints with lacquer paint coatings, developed for carbon plastics, revealed a heavy corrosion of aluminum alloys in contact with carbon plastics and LPC swelling (Fig. 4). The reason for corrosion is a fast cathodic process on carbon plastics, involving hydrogen evolution and raising the coating as fine blisters. As a result, the coating possesses reduced protective properties.

The current density through the contact couple aluminum alloy–carbon plastic (on the basis of Porcher fabric) without protective coating, which relates to the corrosion rate, is 15 mA cm^{-2}. The anodic oxide coating (commercial or newly developed) on the aluminum alloy decreases the current to 0.05 mA cm^{-2}; the current decreases even stronger with the glass fabrics T10 (to 0.00004 mA cm^{-2}) and T64 (to 0.00006 mA cm^{-2}), and sealant (to 0.00008 mA cm^{-2}). Nickel foil is less effective (0.003 mA cm^{-2}) than glass fabric. The current through the cadmium-plated steel–aluminum alloy couple is 3.0 mA cm^{-2} and through the anodic oxide-coated VT6 titanium alloy–aluminum alloy couple is 0.0008 mA cm^{-2}.

The electrochemical research established that the currents through aluminum alloy–carbon plastic couples are most decreased by sealant or glass fabric gasket layers. The samples were subjected to express corrosion fatigue tests involving alternating fatigue loads and exposures in a corrosive medium in the SMC under a constantly sprayed 5% NaCl solution and 35°C. After testing, assessment of the corrosion-induced reduction of fatigue strength was performed. The resulting data are listed in Table 5.

As seen from Table 5, the joints destroy over the aluminum cover plates in the vicinity of central holes. The destruction nucleus is fretting under bolt heads. The maximum endurance decrease (up to 63%) is observed with 30-μm nickel foil gasket layers. With U30MES-5 and VG-9 sealant gasket layers, the decrease of corrosion-induced fatigue is 12–34%. The T64 and T10 glass fabrics have almost no effect on endurance. The scatter is associated with the technology of fabrication of bolt joint samples, specifically, quality of bolt holes and lack of joint coaxiality in part of the samples.

CONCLUSIONS

Research on the corrosion activity of carbon plastics in contact with metal materials showed that carbon plastics cause corrosion of aluminum alloys and cadmium- and zinc-plated carbon steels. Comparative electrochemical research on the corrosion behavior of aluminum alloys in contact with titanium and copper alloys and carbon plastics established the following order of materials in terms of decreasing danger to aluminum alloys: carbon plastic > copper alloys > carbonized steels>titanium alloys. Of the aluminum alloys studied, we found the most vulnerable 1420TG1 alloy and the least vulnerable, coated D16T and 1163T alloys.

For aluminum alloy–carbon plastic couples, the following corrosion protection means should be envisioned.

(1) Before assembly, structural parts made of aluminum alloys and contacting with carbon plastics should be subjected to anodic oxidation in sulfuric acid and subsequent treatment of the coating in a potassium dichromate solution. The surfaces open to the exterior contour should be painted before assembly using the following LPC system: 1 layer of hot-dried EP-0215 primer, 1 layer of cold-dried VG-28 primer, and 2 layers of Aerodur C 21/100 UVR enamel.

(2) For additional protection from contact corrosion in metal–carbon plastic couples, it is recommended to apply a glass fabric (like T10 or T64) shrinked-on during carbon plastic molding, or sealants.

(3) Carbon plastic items should be painted before assembly using the following LPC system: 1 layer of cold-dried EP-0104 primer and then 2 layers of EP-140 enamel.

(4) In assemblies including carbon plastics, anodic oxide-coated titanium alloy fasteners should be used.

(5) Fasteners should be set using VP-1 paste on the basis of a rubber–epoxide oligomer containing corrosion inhibitors.