Corrosion-fatigue failure of tractor trailers metal materials in aggressive environments

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The processes of corrosion-fatigue failure of materials in contact with mineral fertilizers are insufficiently studied. As a result of joint influence of atmospheric corrosion and mechanical loads, about 70 to 80 % of machine parts get out of order, 20 to 25 % of which are failures caused by operating overload due to the strength loss because of atmospheric corrosion. A large part of metal structures of agricultural vehicles used to transport mineral fertilizers is under the direct influence of aggressive environments and dynamic loads that occur during the motion by field roads. Saturated solutions of the most aggressive working environments used in agricultural production, in particular ammonium sulphate and nitrophosphate are investigated to reduce fatigue resistance of ordinary steels groups – St3 and St5 and quality steels – 10 Steel, 15 Steel, 20 Steel, 25 Steel when loaded at all levels. The fatigue endurance limit decreases in comparison with air up to 2.02 times in a solution of ammonium sulphate, and to 2.32 times in a solution of nitrophosphate. In organic fertilizer environments, compared to distilled water, the conditional fatigue endurance limit increased to 9 %. The properties of the given materials as an inhibitor of corrosion-fatigue failure were discovered and proved.

INTRODUCTION

The key factors of fatigue and corrosion-fatigue failure of transport machines metal structures used in agricultural production determine the state of working surfaces, load parameters, environments aggressiveness degrees in consideration of the different kinds of fertilizer, weather conditions, etc. [1-11]. On examining the technical state of agricultural machinery after 3 years of operation, it is observed that corrosion contributes to approximately 80 % of all mechanical failures of assembly units [3, 5-11] (Fig. 1 and 2). The corrosion fatigue failure is the result of additive effects of service loads, environments, and thermodynamic lability of metal structures materials. Corrosion damages and light-gage sheet metal failures change a state of work-piece surface and intensify the wear processes. They significantly degrade tribotechnical properties and corrosion processes, causing a simultaneous decrease in fatigue strength. As a result, the reliability and durabi-

lity of vehicles are significantly reduced. Similar processes occur when operating gas pipelines in corrosive environments [12-18], because of one of the most common materials for oil and gas pipelines is carbon steels.

The processes of corrosion-fatigue failure of materials in contact with organic and mineral fertilizers are insufficiently studied. The absence of reliable data makes it difficult to develop new effective methods of corrosion protection of agricultural fertilizing machines.

a)

b)

Fig. 1. Corrosion-fatigue failures of machine units used in agricultural production

Fig. 2. Welded fatigue failures of light-gauge sheet metal structures of trailers

In particular, in [1, 19, 20], two steels are studied without taking into account the fact that for manufacturing metal structures of this class machinery, the whole range of standard and quality steels are applied. There is a need for experimental research of the whole range of metal materials of tractor-trailers, fertilizing machines, etc. under the influence of corrosive agricultural environments. The results of such research could be used as input data for the objective and quantitative assessment of operability parameters of the given type vehicles.

MATERIALS AND METHODS

For fatigue and corrosion fatigue tests [21-22], the cylindrical specimens (Fig. 3) with a diameter of 10 mm made of standard steels St3, St5 and quality steels 10 Steel, 15 Steel, 20 Steel, 25 Steel under supply condition were used. Chemical composition of tested steels in Table 1. The working body was an aluminum oxide wheel ЭВ25SMIK. After turning, the grinding allowance was 0.35 mm. Rotation velocity of a specimen was 3 m min^{-1} , linear velocity of a stone – 30 m s^{-1} , depth of grinding during the final passage – 0.005 mm/rev , surface roughness $R_z = 2.5 \text{ }\mu\text{m}$.

To eliminate the traces of mechanical grinding and to provide the fine precision of obtained results, the working area of all specimens before testing was polished using a sandpaper and diamond pastes with different dispersion. The same type of manufacturing technology was applied for manufacturing the batch of specimens (Fig. 3). Therefore, the specimen designation was carried out on both specimen holders. The precision of measurements of the prepared specimens working area was 0.01 mm.

Distilled water as a standard test condensate of water or rainwater, saturated solutions of ammonium sulphate and nitrophosphate, mixed liquid manure of cattle and pigs in proportion $\frac{1}{2}$ acted as corrosive environments [1, 4, 19, 20]. Acidity levels of environments before and after the experimental studies were measured by pH meter I-160M. Fatigue tests were carried out on the equipment IMA-5. The specimens were loaded by the scheme of rotating bend; cycle asymmetry coefficient was $R = -1$ [19-22]. A fast-speed counting device before fracture N fixed the number of cycles. Based on obtained data, the Wohler curves were built. Tests started at $\frac{2}{3} \sigma_{\infty}$, incrementally reducing the value to the limit of endurance σ_{-1} within the framework of research (10^7 cycles – when tested in air, $5 \cdot 10^7$ cycles – in environments under study).

Tab. 1. Chemical composition of tested steels

	C	Si	Mn	Ni	P	S	Cr	As	Cu	Fe
Steel 10	0.07 – 0.14	0.17 – 0.37	0.35 – 0.65	<0.25	<0.035	<0.04	<0.015	<0.08	<0.25	~98
Steel 15	0.12 – 0.19	0.17 – 0.37	0.35 – 0.65	≤0.30	≤0.035	≤0.040	≤0.15	<0.08	≤0.20	~98
Steel 20	0.17 – 0.24	0.17 – 0.37	0.35 – 0.65	<0.25	<0.04	<0.04	<0.25	<0.08	<0.25	~98
Steel 25	0.22 – 0.30	0.17 – 0.37	0.50 – 0.80	<0.25	≤0.035	≤0.040	<0.25	<0.08	≤0.25	~98
St3	0.25 – 0.32	0.05 – 0.15	0.4 – 0.65	–	<0.04	<0.05	<0.03	<0.08	<0.3	~98
St5	0.47 – 0.55	0.17 – 0.37	0.5 – 0.8	–	<0.035	<0.04	–	–	–	~98

Fig. 3. General appearance of specimen for fatigue tests

As a research material, 5-15 specimens at a level of stress $(0.95 \dots 1.05) \cdot \sigma_{-1}$ were used. Based on the research results, the fatigue limit was determined. Two specimens under study remained non-failed after reaching the specified database of testing. After examining 10-15 specimens, the fatigue curves were built [21, 22].

RESULTS AND DISCUSSION

The study of ordinary steels St3, St5 and quality steels – 10 Steel, 15 Steel, 20 Steel, 25 Steel proved that in the whole range of loads, the resistance of quality steels to corrosion-fatigue failure in environments of mineral fertilizers, as compared with air and standard test environment condensate (rainwater), was significantly reduced. (Fig. 1, Tab. 2). Less intense impact on the steels fatigue endurance limit of two groups of mixed manure under study compared to mineral fertilizers was noticed. However, the negative impact of environment on the conditional fatigue endurance limit in comparison with the standard test rainwater was not noticed.

The destruction of specimens during rotational bending tests is due to the inability to avoid contact of the conjugated fracture surfaces, which will be formed due to the growth of the fatigue crack arising from the lateral surface of the samples under the influence of alternating cyclic loads. Therefore, the fractures were studied at different, minimum possible levels of maximum stress, in order to minimize the effects of the specified contact at the final stage of destruction of the sample.

The cracks in the air originated in one (at least two) places along the perimeter of the specimen and the

crescent front extended into the depth of its cross section (Fig. 5a). At the same time, the festoons were created at the fracture, across which fatigued grooves were located (Fig. 5b).

The boundaries between the adjacent festoons were indicated at the fracture by ridges of the ductile separation, which often had traces of riveting due to the discrepancy of troughs and ridges when contacting the edges of the crack in the load cycle. The step of these grooves increased as the crack progressed from the outer surface of the specimen to its final destruction, which was ductile by the origin of the cavities, their subsequent growth, and the fusion with the formation on the surface of the typical fossa relief. A significant change in the mechanism of destruction was found under the influence of the studied media. The number of fatigue cracks on the lateral surface of the samples increases significantly, their propagation front changes. As a rule, these cracks extended deep into the cross section of specimens in the form of wedges (Fig. 6a). The higher resolution of the fractures clearly identified the elements of inter- and trans-granular fracture, a significant secondary cracking along the grain boundaries (Fig. 6b,c).

Due to the destruction along the perlite boundaries in common with the ferrite boundaries, the perlite structure can be observed. This specificity of fatigue destruction leads to a decrease in the limit of fatigue with increasing perlite content. the results obtained in the study are in good agreement with the works [23-25]. Similar mechanisms of fatigue and corrosion-fatigue fracture are observed in tubular steels of such chemical composition [26-30] under difficult operating conditions [31-32]. It can be concluded that the detection of the boundaries of the perlite plates became possible only because of the influence of the aggressive components of the investigated media for the reason that such destruction was not observed in the air. When testing samples in distilled water, the classic fatigue fracture mechanism with elements of inter granular cracking prevailed. This is the reason why they have a significantly lower effect on the conditional fatigue limit of Steel 15 compared to the mineral fertilizers obtained in the solutions.

Tab. 2. Fatigue endurance limits of metal structure materials in working environments (MPa)

Steel	Air	Organic fertilizer	Distilled water	Mineral fertilizers	
				Ammonium sulphate	Nitrophosphate
St3	197	139	121	93	85
St5	208	146	127	98	89
10 Steel	192	135	124	95	83
15 Steel	202	143	136	102	90
20 Steel	207	147	135	104	90
25 Steel	219	156	143	111	96

Fig. 4. Fatigue curves of standard steels and quality steels in working environments

Fig. 5. The place of origin of the cracks from the surface of the specimen and the sickle-front of its propagation into the depth of its section (a) and fatigue fracture surface of Steel 15 in the air (b)

CONCLUSIONS

The influence of the most aggressive environments of agricultural production on fatigue fracture of agricultural trailers steel elements is analyzed. In particular, in the whole range of applied loads, the resistance of ordinary steels groups under study – St3, St5 and quality steels under study – 10 Steel, 15 Steel, 20 Steel, 25 Steel to the corrosion-fatigue failure in mineral fertilizers environments compared with air decreased significantly.

In a solution of ammonium sulphate, the conditional fatigue endurance limit of steel quality decreased to 2.02 times, in a solution of nitrophosphate - to 2.31 times as compared with air, and to 1.3 and 1.49 times compared to distilled water. In organic fertilizer environment, the

Fig. 6. Fatigue fracture surfaces of Steel 15 in the medium of saturated nitrophosphoric solution: a) $\times 100$, b) $\times 250$, c) $\times 1000$

conditional fatigue endurance limit increased to 9 % compared to standard test rainwater. The resistance to the corrosion-fatigue failure of ordinary steels occurred to be lower than quality steels. Less intense impact of organic fertilizers on the fatigue endurance limit of both steels compared to mineral fertilizers was noticed.

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