Investigation of strength and corrosion resistance properties of combined packaging materials for metal products

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Abstract
In the paper, strength and corrosion resistance properties of combined packing materials for protection of steel products are studied. It is established that in case of steel products application, the most unfavorable temperature range is the interval (30-40)˚C when growth of vapor transmission rate of packing materials is observed and access of water vapors to metal surface increases. The packing papers containing vapor-phase inhibitors of corrosion have protective effect under the conditions of the increased relative humidity: the index of corrosion does not exceed 5.0 g/m^2.
Key words: COMBINED PACKING MATERIALS, DEFORMATION AND STRENGTH PROPERTIES, CORROSION RESISTANCE PROPERTIES, HUMIDITY, STEEL PRODUCTS

Introduction

Today and in the foreseeable future, metal remains the main constructional material of which different products are made. The main problem of metal products during application, storage and transportation under different conditions is their corrosion [1-2]. According to the experts, corrosion in a year destroys from 25 to 30% of annual output of ferrous metals. It specifies primary importance of problem of metals corrosion prevention, and therefore, big significance of search of optimum packing materials for anticorrosive protection of metals.

The progressive direction in corrosion prevention is development of the packing materials containing inhibitors of corrosion [3-6]. In recent years, this problem has risen especially seriously due to extension of export of steel products. In some cases, the products are transported in open wagons or by sea through the regions with humid tropical climate that is the favorable medium for corrosion processes.

On the one hand, perfect package for steel products should totally exclude access of water vapors and aggressive gases causing corrosion to metal product surface, but on the other hand, it should absorb moisture which is inside after packing of product and condensed in case of temperature differences. Moreover, it should possess the necessary strength properties guaranteeing its safety and preventing of packed hardware from mechanical damages. Package should provide counteraction to different loadings in case of logistic operations.

The packing combined materials containing volatile corrosion inhibitors (VCI), which successfully compete with traditional means of anticorrosive protection (oils, lubrications, varnishes, enamels, etc.), correspond to the criteria stated above. Crepe base paper is carrier of corrosion inhibitor and absorber of condensation moisture. The polymeric covering is a barrier from atmospheric contaminants and moisture. For increase of strengthening properties of packing material, the paper web is reinforced by grid from polypropylene threads.

The purpose of researches consists in study of physical and mechanical and protective properties of packing materials under the conditions of atmospheric corrosion.

For achievement of purpose, the following problems were solved:

- to study physical and mechanical properties of combined packing materials;
- to analyze barrier properties of packing materials;
- to evaluate corrosion-preventing properties of packing papers under the conditions of atmospheric corrosion.

Materials and methods of research

The package papers Fislage (Germany) laminated by polyethylene, reinforced by polypropylene grid and containing volatile corrosion inhibitors were the objects of research (Table 1). Package paper Fislage with N inhibitor is intended for packing of cold-rolled steel, with Z inhibitor is intended for packing of galvanized steel. The composition of volatile corrosion inhibitors (VCI) is confidential.

Table 1. Objects of research

Paper name	Inhibitor	Inhibitor mass, g/m^2	Paper mass, g/m^2
Fislage	Volatile «N»	9,5	159,0
Fislage	Volatile «Z»	12,7	170,0

Deformation and strength properties of the studied materials were determined by the universal electromechanical test machine Walter+baiag with digital control system EDC-120 according to GOST 30436-96 (ISO 1924-2-85).

Materials strength in case of stretching or breaking stress is characterized by strength limit, that is maximum stress σ which is withstood by material without destruction (gap). The breaking strength in case of σ_T (Pa) is determined by formula (1):

$$\sigma_T = \frac{F_{\max}}{S}, \quad (1)$$

where $F_{\max}$ – maximum tensile strength, N;
S – cross-sectional area, m^2.
The relative lengthening of material in case of stretching (%) is determined as ratio of absolute deformation Δl (m) to the initial length of sample of l (m) (2):

$$\varepsilon = \frac{\Delta l}{l} \cdot 100, \quad (2)$$

Vapor transmission rate of combined materials in the range of temperatures from 20 to 60 ˚C was determined in accordance with GOST by 9.507-88. Vapor transmission rate of q is expressed in grams of water vapors which passed through the unit of surface of combined material within 24 hours at the specified temperature and relative humidity (95±5) % and is calculated in g/m^2 for 24 h by formula (3):

$$q = \frac{9{,}6 \cdot 10^7 \cdot \Delta m}{\pi \cdot d_{in}^2 \cdot \tau}, \quad (3)$$

where Δm - mass change, g;
d_{in} – inside diameter of sample, mm;
τ – test time, h.

For evaluation of absorption capacity, samples of package papers were exposed under conditions of various relative humidity, then changes of samples mass were determined gravimetrically.

Under the conditions of various relative humidity, evaluation of protective effect of package papers from atmospheric corrosion of cold-rolled and zinc galvanized steel according to GOST 9.054-75 was carried out.

The metal plates packed into the studied papers were exposed under conditions of various relative humidity within 30 days. Tests with periodic moisture condensation in samples were carried out cyclically. Each cycle consists of two parts. In the first part of cycle samples are affected by air medium with temperature (40±2) ˚C and relative humidity (95±3) % within seven hours. In the second part of cycle, moisture condensation conditions within 17 hours are formed. Corrosion index K (g/m^2) was calculated according to test results by formula (4) [7]:

$$K = \frac{m_1 - m_2}{S \cdot \tau}, \quad (4)$$

where m_1 – initial mass of sample, g;

m_2 - sample mass after tests, g;

S - sample surface area, m^2.

Speed of uniform (general) corrosion ($g/m^2 \cdot w$) is determined by formula (5):

$$V = \frac{m_1 - m_2}{S \cdot \tau}, \qquad (5)$$

Protective effect of corrosion inhibitors Z (%) on loss of control samples mass was determined by formula (6):

$$Z = \frac{V_0 - V}{V_0} \cdot 100, \qquad (6)$$

where V_0 – speed of sample corrosion in case of absence of inhibitor, $g/m^2 \cdot h$;

V – speed of sample corrosion with inhibitor, g/m2 · h.

Results of research and their analyze

The typical deformation curve of package paper Fislage is provided in Figure 1.

The maximum in curve corresponds to rupture of thin polyethylene covering. Further deformation is of stage character due to stretching and break of crepe paper and polypropylene threads.

The relative lengthening of sample of paper Fislage "Z" is insufficient at the destruction point (Table 2), therefore, problems in case of the mechanized package of steel rolls, namely, paper break and discontinuance of package, can appear.

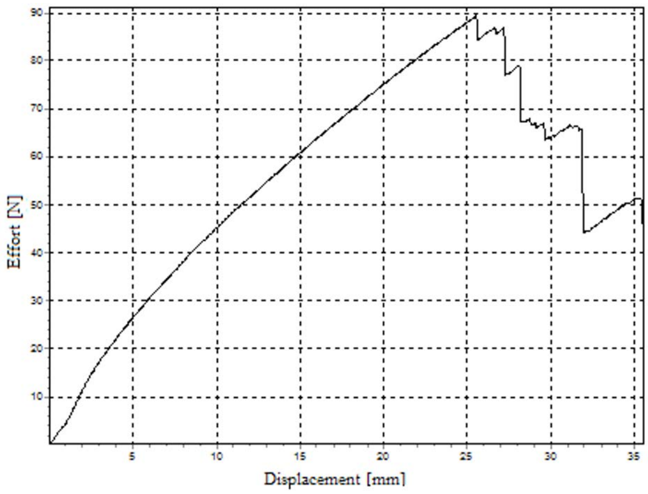

Figure 1. Deformation curve of package paper Fislage

Table 2. Deformation and strength properties

Indices	Type of paper	
	Fislage «N»	Fislage «Z»
Maximum load, N	82,0	82,0
Breaking strength, kN/m	5,4	5,4
The relative lengthening at the destruction point, %	29,0	16,0

The important factor determining the speed of atmospheric corrosion is humidity. The amount of water, which is condensed when cooling on metal surface, depends on the relative humidity. Thus, thickness of the water film, which is formed on iron surface in case of relative air humidity of 55%, is 15 molecular layers, and in case of the relative humidity of 100% is 90-100 layers [2]. The crepe base paper of package material should absorb condensation moisture and therefore prevent development of corrosion process.

Barrier properties of packing materials in relation to water vapors can be evaluated through vapor transmission rate, that is transfer of water vapor through packing material. Driving force of this process is differential of pressures or concentration. Two mechanisms of process of vapor transmission rate are implemented in combined packing material. In polymeric material, transmission is caused by diffusion processes, which are described by the first Fick's law. Molecular diffusion always proceeds in the direction of concentration reduction and depends on properties of diffusing substance, properties of packing material, temperature and pressure [2]. Passing of water molecules through the base paper is of more complex nature that includes the diffusion mechanism of vapors transfer and mechanism of streamline flow submitting to the Poiseuille's law [8].

Temperature dependence of vapor transmission rate of the studied packing papers is provided in Figure 2. In case of temperature increase, growth of vapor transmission rate is caused by the following processes: water molecules form hydrogen bindings with cellulose hydroxyl group that conduces cellulose swelling. In case of further temperature increase, breaking of hydrogen bindings takes place that is followed by growth of kinetic mobility of macromolecules of cellulose, their binding and compacting; consequently, vapor transmission rate is reduced [8].

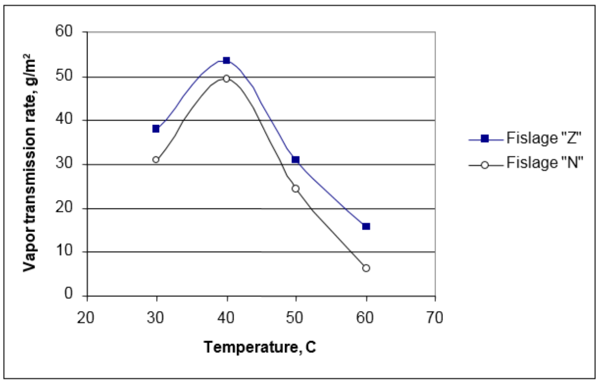

Figure 2. Temperature dependence of vapor transmission rate

Thus, the most unfavorable temperature range from the standpoint of operation is the interval of 30-40 °C when growth of vapor transmission rate is observed and access of water vapors to metal surface increases.

The main benefit of packing materials on paper basis is ability of paper to absorb the moisture which is condensed in package in case of temperature differences. Dependence of mass of packing papers on relative air humidity is presented in Figure 3.

In case of low values of relative humidity, water vapors are occluded forming hydrogen bindings with cellulose hydroxyl group. In case of the relative humidity of 75-85%, certain level of saturation is reached that is followed by devitrification and restoration of structure of cellulose fibers with thin system of pores and capillaries. In these pores and capillaries, condensation of water vapors takes place. The main increase in water absorption is observed in the field of relative humidity higher than 90% in course of process of capillary condensation [8, 9].

The evaluation of protective action of package papers from atmospheric corrosion of cold-rolled and zinc galvanized steel was carried out under the conditions of various relative humidity. Results of corrosion-preventing tests and calculations are presented in Table 3.

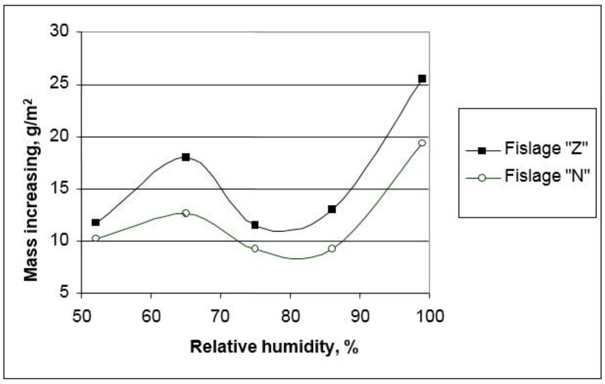

Figure 3. Dependence of papers mass on the relative humidity

Table 3. Results of corrosion-preventing tests under the conditions of various relative humidity

Paper sample	Relative moisture, %	Corrosion products mass, g	Corrosive index K, g/m^2	Corrosion rate V, $g/m^2 \cdot h$	Protective effect of corrosion inhibitors Z, %
Paper without inhibitor	52	0,053	11,8	0,016	-
	65	0,044	8,7	0,012	-
	75	0,178	34,0	0,047	-
	86	0,132	25,1	0,035	-
	99	0,093	17,9	0,025	-
Fislage “N”	52	0,016	3,9	0,005	69
	65	0,017	2,2	0,003	75
	75	0,019	2,8	0,004	91
	86	0,015	3,2	0,004	89
	99	0,017	4,2	0,006	76
Fislage “Z”	52	0,006	1,3	0,002	87
	65	0,013	2,9	0,004	67
	75	0,009	1,9	0,003	94
	86	0,014	3,1	0,004	89
	99	0,008	2,3	0,003	88

According to [10], products of atmospheric corrosion on cold-rolled steel are $FeOOH$, Fe_2O_3 and Fe_3O_4, on zinc galvanized steel they are $2ZnCO_3{\cdot}3Zn(OH)_2$ and $ZnCO_3{\cdot}3Zn(OH)_2$. After exposure under the conditions of the increased relative humidity, the mass of plates made of cold-rolled steel increased. Weight increasing of metal corresponds to the mass of corrosion products, which have good adhesion to metal. The mass of plates made of galvanized steel is generally reduced that demonstrates loss of corrosion products due to their bad coupling with the surface of metal and partial dilution.

Dependence of index of corrosion on the relative humidity for the plates packed into papers Fislage is approximately at the same level - less than 5 g/m^2 (Figure 4) that is caused by protective effect of volatile corrosion inhibitor [2, 3].

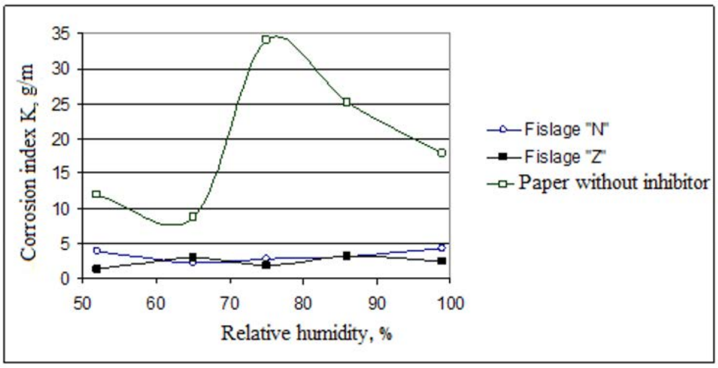

Figure 4. Dependence of index of corrosion on the relative humidity

Corrosion index values for the plates packed into paper without volatile inhibitor of corrosion is much higher. The maximum corrosion corresponds to the relative humidity of 75-80%.

Conclusions

Thus, in course of evaluation of deformation and strength properties, it has been revealed that the relative lengthening of sample of paper Fislage "Z" is insufficient at the destruction point (Table 2), therefore, problems in case of the mechanized package of metal products can appear.

Thus, it has been established that the most unfavorable temperature range from the standpoint of operation is the interval of 30-40 °C when growth of vapor transmission rate is observed and access of water vapors to metal surface increases.

The low absorbing ability of papers in the field of relative humidity of 75-85% conduces formation of thin film of water on the surface of metal plate that leads to emergence and development of corrosion process.

The packing papers containing vapor-phase inhibitors of corrosion have protective effect under the conditions of the increased relative humidity: the index of corrosion does not exceed 5.0 g/m^2.

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