Durability of Polymer Powder Coatings

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Abstract. The durability of polymer powder coatings is considered. The features of the impact on coatings during their operation of the environment, loads from the side of the substrate on the surface of its contact with the coatings, parameters that depend on the chemical composition and structure of the coating material are briefly analyzed. The thickness of the coating stands out as the main indicators of durability; a function that characterizes the continuity, strength, corrosion resistance, and its other properties; adhesive strength. It is proposed to use a generalized (integral) criterion for a comprehensive accounting of these indicators. An equation is written to assess the durability of the considered coatings, in a particular case, a formula is given for calculating their permissible operating time.

1 Introduction

The beginning of the industrial use of polymer powder paints dates back to the 50s of the last century. At present, they are successfully used at enterprises of mechanical engineering, the fuel and energy complex, chemistry, agriculture and communal services, and many other industries. There are two main types of polymer powder materials: thermosetting and thermoplastic powder compositions (PPC). Coatings based on thermosetting PPC are highly resistant to acids, alkalis, and other chemically aggressive substances; increased mechanical properties: elasticity, impact strength, as well as adhesive strength indicators. Thermoplastic powder compositions are convenient for storage, are characterized by a short coating formation cycle, better sanitary and hygienic working conditions, and less fire hazard. In addition, they are resistant to wear, have high electrical insulation and decorative performance [1, 2].

Undoubtedly, a very important characteristic of the operational properties of polymer powder coatings is their durability. In accordance with the regulatory documents, the durability of coatings is determined by lightfastness, resistance to aggressive liquid media, atmospheric factors (pressure, temperature, humidity, etc.) [3-6]. With regard to equipment, technological installations, technical systems of the oil industry, as the main factors affecting the durability of the considered coatings, an aggressive environment, temperature and mechanical loads are distinguished [7]. Ultimately, durability is the lifetime of coatings during which they are able to perform the required functions.

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For the sake of certainty, let us dwell on the case when polymer powder coatings are operated in air, respectively, a gaseous medium containing oxidizing agents acts on their outer surface: oxygen, ozone; chemically active substances (pollution); water in the form of drops, steam; mechanical (abrasive) impurities. Further, the coatings can be affected by light, ultraviolet, infrared (radiation) radiation; temperature loads; loads in the form of pressure, concentrated forces and moments, impacts, etc. In general, four main factors act on the outside of the coating - air, radiation, temperature, mechanical stress.

2. Main part

In order to further, when assessing the durability of coatings, it would be possible to use the methods of mathematical modeling, let us denote through τ_k the time characterizing the durability, through Q_a, Q_r, Q_t, Q_m – the intensity of the impact on the outer surface of the coating of air, radiation, temperature and mechanical loads. Moreover, each of these indicators is integral, reflecting, as a rule, the effect of several factors. For example, Q_a depends on the concentration of oxidants, chemically active substances, humidity, mechanical impurities in the air; Q_t – from the actual ambient temperature, temperature differences, the magnitude of heat fluxes. If it is required to assess in more detail the influence of individual factors, then the values of Q_a, Q_r, Q_t, Q_m can be interpreted as vectors, the components of which estimate the intensity of the impact on the outer surface of the coating of these factors.

At the same time, from the side of the substrate, on the surface of its contact with the coating layer, which we will call the inner surface, factors of a chemical and physical nature can act, let us denote their intensity by q_c and q_f , respectively, as well as temperature and mechanical factors characterized by the intensity q_t and q_m , respectively.

Finally, a set of so-called internal factors should be distinguished, due to the chemical composition of the coating, the presence of weak bonds, microcracks and pores, internal stresses, etc. The degree of influence of these factors on the performance of the material will be denoted by m_c, m_s, m_p, m_e , etc.

Obviously, during the operation of coatings, almost all of these factors depend to one degree or another on the time τ :

$$\begin{aligned} Q_a &= Q_a(\tau), Q_r = Q_r(\tau), Q_t = Q_t(\tau), Q_m = Q_m(\tau); \\ q_c &= q_c(\tau), q_f = q_f(\tau), q_t = q_t(\tau), q_m = q_m(\tau); \\ m_c &= m_c(\tau), m_s = m_s(\tau), m_p = m_p(\tau), m_e = m_e(\tau). \end{aligned} \quad (1)$$

To simplify the subsequent entries, the intensity of the combination of factors acting on the outer surface of the coating will be denoted by $Q_0 = Q_0(\tau)$; on the inner surface (the contact surface of the coating layer and the base) – $q_b = q_b(\tau)$; the intensity of the factors characterizing the properties of the coating material – $m_i = m_i(\tau)$. Moreover, Q_0, q_b, m_i are essentially functionals:

$$Q_0 = Q_0(Q_a, Q_r, Q_t, Q_m), q_b = q_b(q_c, q_f, q_t, q_m), m_i = m_i(m_c, m_s, m_p, m_e, \dots). \quad (2)$$

In the presence of factors, the action of loads Q_0, q_b on the coating, mechanical and physicochemical processes occur in the coating material, it can break down, peel off from the substrate, etc. [6]. In fact, aging of the coating material occurs, which has been studied and described in sufficient detail in the scientific and technical literature [8-10]. When using

the data presented in it, the following circumstances must be taken into account: the relatively small thickness of the coating layer, the impact on it of both loads from the outer surface and those acting on the inner surface of the contact of the coating layer with the substrate. Accordingly, the adhesion of the coating material to the substrate should be considered, and the adhesion strength should be evaluated [11-13].

In this situation, it is advisable to choose as indicators characterizing the durability of polymer powder coatings, the thickness of the coating H_c ; functional G_c , describing the continuity, strength, corrosion resistance, other performance properties of the coating material, as well as the adhesion strength F_a . These indicators, like all the previous ones, also depend on the operating time τ :

$$H_c = H_c(\tau), G_c = G_c(\tau), F_a = F_a(\tau). \quad (3)$$

Obviously, the time for them to reach the critical dependences H_{ck} , G_{ck} , F_{ak} , due to the corresponding requirements for the functionality of the considered coatings, is different. But if each of them is important, it is naturally desirable to take all of them into account when assessing the durability of coatings τ_k . One of the possible ways to solve this problem is to construct a generalized (integral) criterion

$$K = K(\tau) = F(H_c(\tau), G_c(\tau), F_a(\tau)). \quad (4)$$

In the simplest case, the functional K can be represented as:

$$K = K(\tau) = \alpha H_c(\tau) + \beta G_c(\tau) + \gamma F_a(\tau), \quad (5)$$

where H_c , G_c , F_a – normalized functions; α , β , γ – weight coefficients characterizing the significance of the corresponding indicator ($0 \leq \alpha \leq 1$, $0 \leq \beta \leq 1$, $0 \leq \gamma \leq 1$; $\alpha + \beta + \gamma = 1$). In particular, if $\alpha = \beta = 0$, $\gamma = 1$, then the adhesion strength of the coating is dominant. If, for example, $\alpha = 0.75$, $\beta = 0.25$, $\gamma = 0$, the focus is on the wear of the coating material during its operation. In our opinion, the most effective way to establish the values of these coefficients is an expert one.

Since, as noted above, it is required that the values of the indicators H_c , G_c , F_a are not less than the critical H_{ck} , G_{ck} , F_{ak} , the equation for finding the value K follows from the expression for the criterion τ_k :

$$K(\tau_k) = K_k. \quad (6)$$

Here $K_k = \alpha H_{ck} + \beta G_{ck} + \gamma F_{ak}$ – a parameter characterizing the limitations imposed on individual indicators of the durability of coatings and the significance of each of them.

Practice shows that by the end of the service life of the coatings, the functions $H_c(\tau)$, $G_c(\tau)$, $F_a(\tau)$ are close to linear, respectively,

$$H_c(\tau) = a_0 + a_1\tau, G_c(\tau) = b_0 + b_1\tau, F_a(\tau) = c_0 + c_1\tau, \quad (7)$$

where the coefficients are a_0 , a_1 ; b_0 , b_1 ; c_0 , c_1 are determined as a result of analysis of literature data, experiments, theoretical research.

From this it is clear that the durability of polymer coatings can be calculated by the formula:

$$\tau_k = (K_k - D_0)/D_1, \quad (8)$$

where $D_0 = \alpha a_0 + \beta b_0 + \gamma c_0$, $D_1 = \alpha a_1 + \beta b_1 + \gamma c_1$.

3 Conclusions

Taking into account the specifics of obtaining polymer powder coatings, their properties, operating conditions, an approach is proposed, and the main provisions for assessing the durability τ_k of these coatings are developed. Provided that the thickness of the coating layer and the strength of adhesion are chosen as the main indicators of durability, an equation for finding τ_k is written. In the particular case of a linear dependence of these indicators on the operating time, setting their critical values, a formula for calculating the value τ_k is determined.

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