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Cavitation-erosion resistance of eutectic coatings in sodium chloride solution

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Abstract

The paper presents original research results related to the resistance of proprietary eutectic coatings applied to C45 structural steel to cavitation-erosion wear. This type of wear is encountered in devices operating in the chemical, petrochemical, heat and power industry and other industries. The research was conducted on a unique measuring stand developed by the authors. The research was conducted in a highly corrosive environment, i.e. sodium chloride solution. As a result of the research work, curves of the change in the electrode potential of C45 steel with different surface conditions and its polarization curves were obtained. Thanks to these curves, it was possible to determine the optimal method of protecting the tested steel against cavitation-erosion wear.

Keywords: eutectic coatings, structural steel, cavitation-erosion wear, sodium chloride, test bench

Introduction

To the most dangerous types of corrosive destruction of devices operating in the chemical, petrochemical, heat and power industry and other industries include destruction under the influence of stress corrosion. The interaction of corrosive environments with metal working under mechanical load leads to irreversible chemical processes and phenomena at the metal - environment boundary and reduces the durability and reliability of responsible parts of machines, devices and building structures[1–3].

In the literature, the results of numerous studies show that when the environment has a micro-impact effect on the metal, corrosion processes increase rapidly. This is due to a number of reasons [4–6]. The first reason can be indicated that during micro-impact, the diffusion of oxidants to the working surface of the part increases with simultaneous outflow of dissolved metal ions from it. Another reason is that the adsorption layers of secondary structures - corrosion products - are subject to intensive destruction. Thirdly, during micro-impact load, a mechano-chemical effect is observed. Depending on the degree of micro-impact impact, the role and significance of each of the above factors changes significantly [7–9]. It can be seen that at a low intensity of micro-impact loading, the destruction of metal during cavitation-erosion fatigue is explained by the influence of the first two factors. With the increase of external influences, i.e. with deformation and hardening of the surface layer of the part, the third factor appears [10,11]. In order to increase the resistance to cavitation-erosion wear of metal surfaces operating in a corrosive environment, eutectic coatings are applied.

The nature of cavitation-erosion fatigue significantly changes depending on the simultaneous impact of such factors as the intensity of micro-impact load and corrosive activity of the environment. In the case of low corrosive activity of the environment and high intensity of micro-impact impact, the mechanical factor dominates. In the case of low external impact and high corrosive activity of the environment, on the contrary, the corrosive factor dominates. In the conditions of medium intensity of micro-impact load and high or medium corrosive activity of the environment, the intensity of corrosive processes increases. In this case, both mechanical and corrosive factors appear, the role of which was confirmed by the following research results.

In the case of cavitation-erosion wear process in a corrosive environment, hydrogenation processes can have a significant impact [12]. The negative influence of hydrogen on plasticity, fatigue strength and other mechanical properties of metals is known. As a result of high pressures and temperatures at the point of contact of the metal with the liquid, intensive plastic deformation of the surface layer of the metal, destruction of passive layers, it is possible to occur cathodic reactions with the release of hydrogen, the influence of which on the process of cavitation-erosion wear process is different [13–15]. In the initial phase of wear and at low hydrogen concentration, it increases microhardness and abrasion resistance. When the process duration and hydrogen amount increase, wear resistance decreases. However, in relation to this work, such a conclusion requires further research [16].

The possibilities of increasing the durability of machine parts subject to intensive cavitation-erosion wear in corrosive environments by applying protective coatings with eutectic composition and structure are presented below. Moreover, the study of electrochemical processes during cavitation-erosion fatigue in various environments using the potentiostatic method confirms that the micro-impact interaction of liquids has a significant effect on the nature and intensity of electrode reactions.

Experimental

The tests were carried out on two different eutectic coatings developed by the authors of the work and on a sample made without a eutectic coating. The cavitation-erosion resistance of the developed coatings was tested taking into account the mutual interaction of mechanical and corrosive factors [5,17,18]. The experiment consisted of two stages: determination of electrochemical characteristics, which were used for theoretical prediction of coating resistance. In the next step, wear tests were performed. The cavitation-erosion resistance of C45 steel with eutectic coatings was tested in a 3% aqueous solution of NaCl on a specially designed measuring station (Fig. 1) using potentiostatic method.

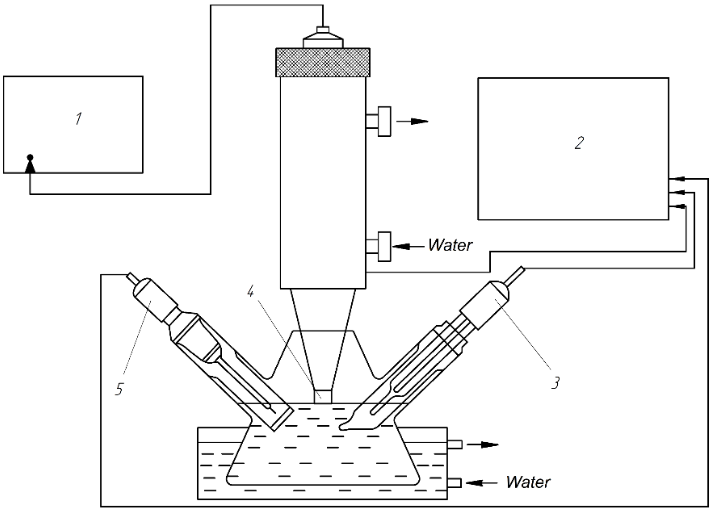

Fig. 1. Schematic diagram of the device for cavitation-erosion wear of coatings with simultaneous study of electrochemical processes:
1-ultrasonic vibration generator with magnetostrictive vibrator, 2-potentiostat, 3-saturated coamel electrode, 4-working electrode (test sample), 5-reference electrode (platinum) [12]

The experimental device consists of three main parts (Fig. 1): an ultrasonic vibration generator 1 with a magnetostrictive vibrator, an electrochemical cell 4, in which a working electrode (sample) is placed, attached by means of a thread to the magnetostrictive vibrator, and a potentiostat 2 model P-5827M. The diameter of the samples, which also serve as working electrodes, is 0.01 m. Before connecting to the magnetostrictive vibrator, the samples were pre-grinded using M20 sandpaper.

Results and Discussion

Based on the results of measurements of the general electrode potentials of the tested 45 steel samples in the corrosive-erosive wear process in a 3% NaCl aqueous solution (Fig. 2), it can be seen that the eutectic coatings of the powder mixtures used in the tests are of the cathode type.

The potential values almost do not change with time. Comparing the results of measurements of electrode potentials of some eutectic coatings during cavitation-erosion wear in a 3% aqueous solution of NaCl and in this environment in static conditions, one can notice differences in their kinetics when using ultrasonic vibrations from ordinary corrosion. This difference is due to the fact that in the conditions of cavitation-erosion wear, diffusion processes are present, intensified by acoustic currents in turbulent flows.

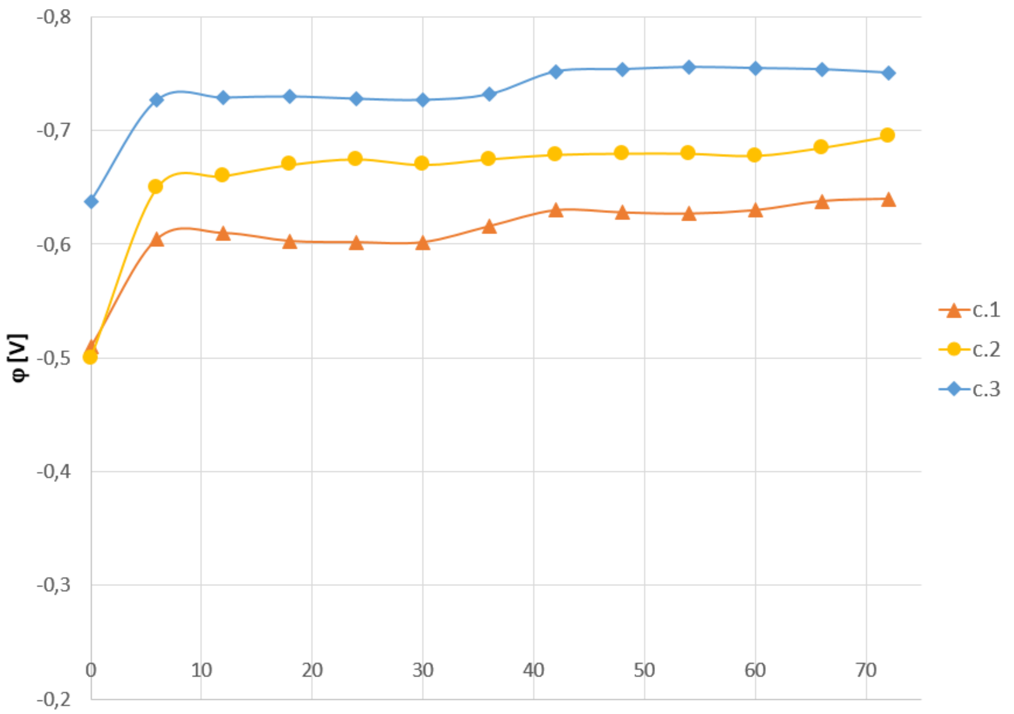

Fig. 2. Change in the electrode potential of C45 steel without coating (c.1) with eutectic coatings from mixtures No. 1 (c.2) and No. 2 (c.3) during cavitation-erosion wear in a 3% aqueous NaCl solution

The destruction of the forming adsorption layers, corrosion products, mechanical destruction of the forming micro irregularities and other phenomena are observed.

Conclusions

The high resistance of the coating of the mixture No. 1 is confirmed by the test results (Table 1). The cavitation-erosion resistance of this coating in a 3% aqueous solution of NaCl is the highest and shows good compliance with the anticorrosive and electrochemical properties of the coating in this environment under static test conditions. High protective properties occur due to the structure and phase composition, represented by solid solutions of chromium in α-iron, nickel and manganese in γ-iron, as well as insignificant amounts of the $Fe_{0.4}Mn_{3.6}C$ phase.

Table 1

Cavitation and erosion resistance of steel 45 in various environments

Coating type	ΔM *10^{-6}, kg		
	Distilled water	3% NaCl*	3% NaCl**
Without coating	3.2	6.2	12.9
Eutectic from the mixture			
No. 1	0.7	13.1	29.8
No. 2	1.7	10.8	25.1
		*Research time $36 \cdot 10^2$ s	**Research time $72 \cdot 10^2$ s

Since the hardness of the eutectic coating of the No. 2 mixture is higher than that of the No. 2 mixture, the resistance characteristics of the coating of the base mixture are higher than those compared. This agrees well with the data [12] regarding the wear resistance of eutectic coatings. When exposed to a corrosive environment (3% NaCl solution), the mechanism of cavitation-erosion wear changes significantly. In this case, both the corrosive and mechanical factors play the main role, with the corrosive factor dominating (it is known that as a result of the micro-impact impact of the aggressive environment, the intensity of the corrosive factor may be proportional, smaller or larger in comparison to the intensity of the mechanical impact). In connection with this, the described electrochemical processes during cavitation-erosion wear of coatings are confirmed, which explain the resistance characteristics of the tested coatings.

It is worth mentioning the corrosion-fatigue nature of the destruction of the tested coatings, which in the case of uncoated steel is visible in the increased occurrence of surface defects such as pores, cracks and others. In contrast to eutectic coatings, where the uniform destruction of the hardened layer takes place over the entire surface, in the boronized coating the destruction starts from the pores and then runs along the grain boundary of the diffusion layer towards the ferrite or pearlite that make up the matrix with further splitting of the coating zone.

In conclusion, it can be noted that during the cavitation effect of a liquid environment on the surface of the sample, intense short-term pressures develop, the duration of which is 10^{-5} s. Only the surface layer of the metal takes part in resisting the dynamic effect of the environment, the depth of which, depending on the intensity of the effect and the properties of the metal, can range from several micrometers to several millimeters [11,19]. Therefore, applying coatings of relatively large thickness and high hardness, continuity and plasticity to the metal surface can be an effective means of increasing the durability of steel products under contact loading. The results of tests of cavitation-erosion resistance of eutectic coatings with these properties confirm the validity of their use for these purposes.

Thus, the factor responsible for long-term operation of machine parts under contact load in cavitation conditions is not the high mechanical properties of steel with a coating, but its strength. This can be explained by the fact that it is not the macroscopic characteristics of this coating, but the ability of the microvolume of its surface layer to resist the influence of the surrounding environment, which can provide the resistance of the part under similar load conditions. At the same time, it is necessary to ensure the structural uniformity of the surface layer of the produced coating.

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Пашечко М., Голубець В., Зубжицький Я., Тісов О. Кавітаційно-ерозійна стійкість евтектичних покриттів в розчині хлориду натрію

У статті наведено оригінальні результати досліджень щодо стійкості запатентованих евтектичних покриттів, нанесених на конструкційну сталь C45 до кавітаційно-ерозійного зношування. Цей вид зносу зустрічається в пристроях, що працюють в хімічній, нафтохімічній, теплоенергетичній та інших галузях промисловості. Дослідження проводились на унікальному вимірювальному стенді, розробленому авторами. Дослідження проводили у висококорозійному середовищі, тобто розчині хлориду натрію. В результаті проведених досліджень отримано криві зміни електродного потенціалу сталі C45 з різними умовами поверхні та її поляризаційні криві. Завдяки цим кривим вдалося визначити оптимальний спосіб захисту досліджуваної сталі від кавітаційно-ерозійного зношування.

Ключьові слова: евтектичні покриття, конструкційна сталь, кавітаційно-ерозійне зношування, хлорид натрію, випробувальний стенд