

B. KALANDYK*, J. KALANDYK**

A METHODOLOGY OF EXPERIMENTAL RESEARCH ON CORROSIVE-EROSIVE WEAR BEHAVIOUR OF IRON ALLOYS IN MINE WATER

METODYKA EKSPERYMENTALNYCH BADAŃ ŻUŻYCIA KOROZYJNO-EROZYJNEGO STOPÓW ŻELAZA W WODACH KOPALNIANYCH

The paper presents a methodology applied in testing the wear behaviour of selected iron alloys used for the components of pumps handling brine from mine workings. The complexity of phenomena occurring during actual flow of the brine through a pump justifies the need to build a laboratory test stand equipped with the model pump, imitating the conditions of industrial operation. In model pump, in which a jet of brine containing different concentrations of Cl ions and particulates is flowing, the surface degradation of samples corresponding to the degradation of industrial pump components takes place.

The programme of research aimed at the determination of corrosive-erosive wear behaviour of Cr-Ni cast steels (18Cr-9Ni, 19Cr-11Ni-2Mo, F-A (24-27%Cr-5-6%Ni-2.5-2.8%Mo) and cast irons of Zl250 and ZsCu1.0 grade. The measure of wear was the loss of weight and changes in surface condition determined by scanning electron microscope (SEM) equipped with energy dispersive X-ray analyser (EDS) manufactured by EDAX company.

Among the examined materials, the best wear resistance (the lowest wear rate) was observed in ferritic-austenitic (F-A) cast steel (24-27%Cr-5-6%Ni-2.5-2.8%Mo).

Keywords: Cast iron, Stainless cast steel Cr-Ni, Corrosive-erosive wear

W pracy zaprezentowano metodykę badań stopnia zużycia wybranych stopów żelaza stosowanych na elementy pomp, transportujących solankę z wyrobisk kopalnianych. Złożoność zjawisk występujących podczas rzeczywistego przepływu solanki przez pompy, uzasadnia potrzebę budowy laboratoryjnego stanowiska badawczego wyposażonego w modelową pompę imitującą warunki panujące w pompach przemysłowych. W modelowej pompie, w warunkach przepływu solanki o różnym stężeniu jonów Cl i cząstek stałych, ulegają degradacji powierzchnie próbek odpowiadające elementom składowym pomp przemysłowych.

W programie badań określono zużycie korozyjno-erozyjne staliw z grupy Cr-Ni (18Cr-9Ni, 19Cr-11Ni-2Mo, F-A (24-27%Cr-5-6%Ni-2.5-2.8%Mo) i żeliw Zl250 i ZsCu1.0. Miernikiem zużycia jest zmiana masy i stanu powierzchni określana za pomocą mikroskopu skaningowego (SEM) wyposażonego w analizator dyspersji energii promieniowania rentgenowskiego (EDS) firmy EDAX.

Spośród badanych materiałów najmniejszą szybkość zużycia odnotowano dla staliwa ferrytyczno-austenitycznego (F-A: 24-27%Cr-5-6%Ni-2.5-2.8%Mo).

1. Introduction

The wear and tear behaviour of cast parts of pumps is of a very complex character, mainly due to the diversity of process parameters and their mutual relationships. The complexity of the effects is additionally enhanced by difficulties in direct observation of the examined area where, during the flow of brine, various phenomena occur [1-3].

The main objective of the research methodology presented in this paper is to determine the corrosive-erosive wear degree of materials used

for the pumps operating in the extractive industry. Elements of pumps (e.g. impellers) used for the pumping of mine water are usually made from the high-alloyed stainless cast steel of 18Cr-9Ni or 19Cr-11Ni-2Mo grade; housings are made from Zl250 and ZsCu0.1 cast iron [4-6]. However, in current practice, more and more often items of this type are manufactured from the modern chromium – nickel cast steel grades of a ferritic – austenitic structure, characterised by the improved corrosion resistance and durability combined with the reduced percent content of nickel in short supply [7,8].

* DEPARTMENT OF CAST ALLOYS AND COMPOSITES ENGINEERING, FACULTY OF FOUNDRY ENGINEERING, UNIVERSITY OF SCIENCE AND TECHNOLOGY, 30-059 KRAKÓW, 23 REYMONTA STR, POLAND

** DEPARTMENT OF FOUNDRY PROCESSES ENGINEERING, AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY 30-059 KRAKÓW, 23 REYMONTA STR, POLAND

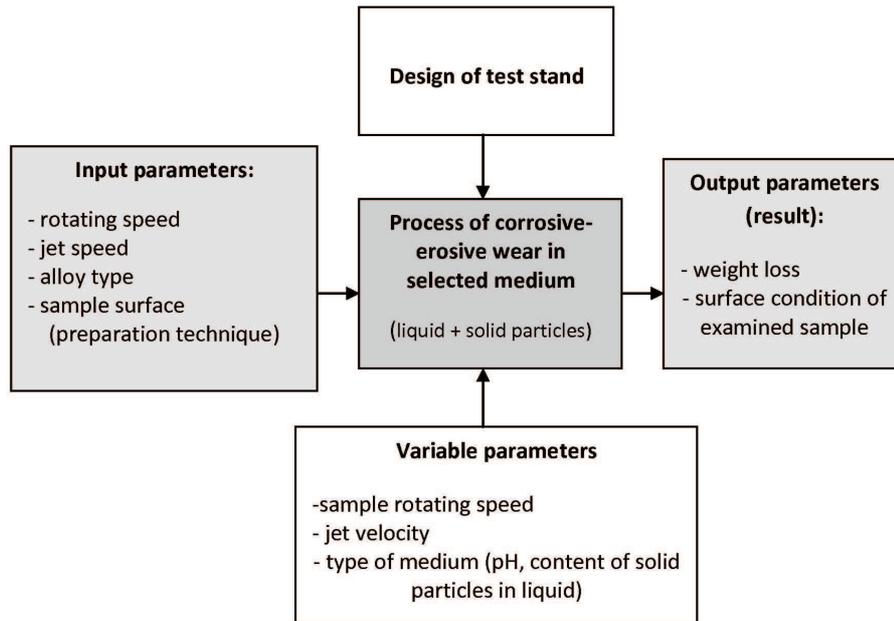


Fig. 1. Methodological scheme of corrosive-erosive studies

The rate of corrosive – erosive wear and tear is largely determined by the degree of aggressiveness of the medium, by alloy grade used for the cast pump elements, and by the type of heat treatment. Based on the literature [1,2,3,10], a methodical pattern of corrosive- erosive tests was developed (Fig. 1), used next as a basis for design of an experimental stand and development of test programme.

In the test stand design, the leading role is played by a model pump in which the process of wear takes place. The pump chamber is made of a transparent material (organic glass), which facilitates observations of the brine flow. In the pump housing chamber, samples are placed in a position creating the streamline, impact and longitudinal tangential flow. Thus the flow has all the features of a turbulent flow.

In adapted model, the variable parameters of the corrosive-erosive wear process are: type of alloys (or one and the same alloy after different variants of heat treatment or after different technological treatments is used), type of medium (pH; presence of Cl ions),

solid particles content in total volume of the wear medium, and medium jet velocity.

2. Methods of investigation

The research programme covered commercial iron alloys used by the domestic foundries as a material for cast pump elements (Cr-Ni cast steels, ZI250 and ZsCu0.1 cast irons). Chemical compositions of the examined alloys are presented in Table 1. Samples for the investigations were taken from industrial melts, and in the case of F-A cast steel – from a laboratory melt. The corrosive medium was mine water containing 6700 mg/dm^3 of Cl⁻ ions and 0.6 g of solid particles in 100 ml of brine. The research methodology included two steps: preliminary studies and basic research. The aim of the preliminary studies was to select the test parameters and adjust them to the type of the examined material; the test time was 90 hours. Basic research covered the time of 430 test hours with the sample rotating speed of 750 rev/min.

TABLE 1

The chemical composition of examined iron alloys (wt %)

Designation	C	Mn	Cr	Ni	P	S	Other
18Cr-9Ni	0.16	0.32	19.8	9.01	0.001	0.005	0.02%Mo
19Cr-11Ni-2Mo	0.048	0.81	19.7	11.7	0.001	0.0014	2.0%Mo
F-A (W3)	0.041	0.89	27.3	5.97	0.001	0.0047	2.57%Mo
F-A (WP5)	0.035	0.96	24.3	5.42	0.010	0.010	2.8%Mo
ZsCu1.0	3.3	0.4	–	–	< 0.1	< 0.1	1.1%Cu, 2.2%Si
ZI250	3.2	0.8	–	–	< 0.1	< 0.1	1.7%Si

Based on the results of preliminary studies, the effect of sample rotating speed and medium jet impact on the rate of erosion and corrosion was confirmed.

Changes that took place on the sample surface after tests and chemical composition in corroded regions were analysed under a scanning electron microscope (SEM) equipped with energy dispersive X-ray analyser (EDS) manufactured by EDAX. The phase analysis of the products of corrosion was made on X – ray diffractometer Krystallflex 4H (tube $\lambda_{Cu}=1.54 \text{ \AA}$; 25 kV; 30 mA).

3. Description of stand for erosive-corrosive tests

The structure of the test stand includes the following assemblies:

a) Laboratory pump – includes the following parts: cylindrical container; rotating disc adapted to simultaneous testing of 8 samples (20×15 mm) mounted in respective seats (Fig. 2a). In the lid of the container there is a blade, which increases the mixture turbulence (Fig. 3), and a nozzle with Venturi tube mounted in direction perpen-

dicular to the sample front surface. It directs the brine jet fed by the circulating pump to the surface of the rotating samples.

- b) Disc drive – this is a three-phase 0.75 kW power motor fed from an inverter. Its use enables control and adjustment of the rotary speed in a range from 100 to 3000 rev/min. The jet flow in a nozzle is ensured by a pump of 60 l/min delivery. The system enables simulation of corrosive-erosive type phenomena and of cavitation erosion.
- c) Installation forcing brine circulation – includes the following parts: circulating pump, brine return container, and stainless steel fittings.

The medium is a mixture of liquid (for example brine type: Cl-Na-Ca [11]) and coal dust from the mine pump station. The use of the stand enables conducting tests in several variants:

- only the disc with mounted samples is rotating in the medium,
- the disc with mounted samples is rotating in the medium and the jet of medium is simultaneously striking the front surface of samples,
- the jet of medium is striking the disc placed in fixed position.

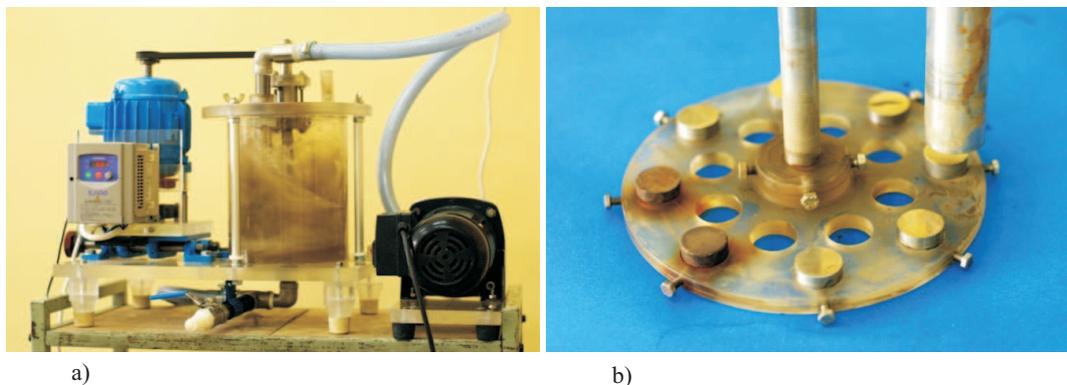


Fig. 2. General view of the stand for corrosive-erosive testing a), view of the disc with mounted samples (after 90 hours) b)



Fig. 3. General view of the medium movement in cylinder during test

4. Results and discussion

The results obtained in the studies were grouped according to the following criteria:

- sample weight loss as a result of corrosive-erosive effect of the medium,
- surface condition of the examined alloy samples upon completion of the studies.

In the case of the first criterion, the results indicate a relationship between the degree of wear and the chemical composition of alloys. After 90 test hours, the samples of cast iron were characterised by the weight losses amounting to 0.3-0.5% of the initial weight, which indicated advanced general corrosion on all surfaces. On the other hand, the group of Cr-Ni cast steels (used mainly for the cast pump impellers) did not show any changes in the weight after 90 hours. No symptoms of a general or local corrosion have been observed. Only after 430 hours, the greatest weight losses in the group of Cr-Ni steels were reported for the conventional 18Cr-9Ni cast steel (0.042% of the starting weight). Lower weight losses showed 19Cr-11Ni-2Mo cast steel. Practically no weight losses were observed in the case of two-phase ferritic-austenitic (F-A) cast steel (Fig. 4). This fact can be due to a higher content of the ferritic phase, compared to 18Cr-9Ni and 19Cr-11Ni-2Mo cast steels. The ferritic phase raises not only the strength but also hardness of the ferritic-austenitic cast steel. In this group of cast steels, the time of corrosive-erosive test should be made longer. The low content of solid particles in the mine water used for the research did not cause the sufficiently intense erosive effects on the surfaces of the examined iron alloys. Therefore, it seems advisable to consider the need for using in the investigations a controlled amount of hard particles of e.g. SiC of the previously known grain size.

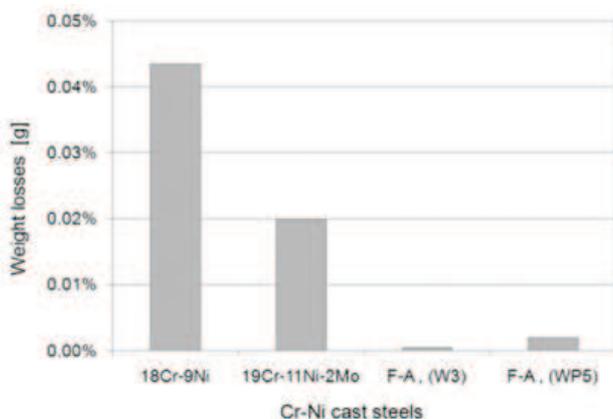


Fig. 4. Weight losses in the Cr-Ni cast steel after 430 hours of test

The results of the examinations of the surface condition, which was the second criterion in an assessment of the investigated iron alloys, have revealed that the most degraded surfaces were in ZI250 and ZsCu1.0 cast irons. After only 90 test hours, an advanced corrosion process was observed to take place on all sample surfaces (Fig. 5). Qualitative and quantitative analysis of solid corrosion products formed on the investigated cast iron surfaces indicated a local diversification of elements concentration. The presents detections of areas rich in such elements as: Fe (~34 wt%), O (~50 wt%), with a lower content of Ca (~5 wt%), Cl, Si, Al (~2-3 wt% each) suggests the presence of iron oxides in corrosion products, (Fig. 5b) see also ref. [5,12,13]. The second type constituted areas was rich in Ca (~27 wt%), Fe (~26 wt%), O (~41 wt%) and contained also Cl (~2.5 wt%), (Fig. 5c). The performed research indicates that Cl⁻ ions, originated from the brine, are adsorbed on corrosion products. Peaks from Fe and Cl observed in Fig. 5b, can also suggest the presence of iron chlorides (FeCl₃ or FeCl₂). A phase analysis performed on a higher amount of pulverised corrosion products also supports this idea. However, it would require higher amount of the number of samples, due to breaking away of corrosive layers in a violently moving brine.

A phase analysis performed by means of X-ray diffraction on the obtained corrosion products indicated mainly occurrence of calcium carbonate CaCO₃ (Fig. 6). Combining this result with the SEM/EDS studies shown in Fig. 5c one can say that CaCO₃ should also be present in corrosion products. The lack of peaks from iron oxides on the diffraction pattern (Fig. 6) can be due to two causes. Firstly, the iron oxides amount in the pulverised material is less than 5%, and secondly, the iron oxides can occur not only in the crystal form but also in the amorphous one, which is not revealed by the X-ray diffraction.

On the basis of the obtained results the significant influence of the chemical composition of a highly mineralised brine on the structure and chemical composition of corrosion layers being formed on surfaces of the investigated cast iron, can be stated.

The conducted visual assessment of the surface of the tested alloys confirmed the destructive effect of brine jet flowing from a nozzle on the volume of corrosion products as compared to an opposite sample surface.

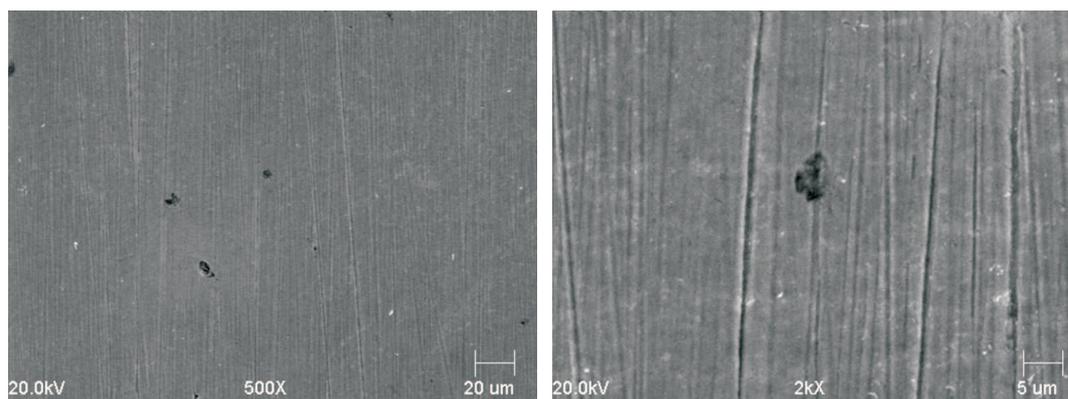


Fig. 7. Surface of F-A (W3) cast steel sample

In the case of samples of Cr-Ni cast steel the presence of small corrosion sources (mainly in the vicinity of non metallic inclusions) combined with polishing of flat surfaces, characterising corrosive-erosive medium influence, was found. A lack of a corrosion products layer results from a high resistance of this group of alloys to a corrosive influence of medium containing Cl^- ions and to a destructive effect of a brine jet (Fig. 7).

In the group of Cr-Ni cast steels, the effect of chemical composition (Cr, Ni and Mo) on the cast steel corrosion resistance in a medium of brine containing Cl^- ions was also examined. It was observed that, compared to other conventional alloys used for pump elements, the samples of two-phase F-A cast steel (24-27%Cr-5-6%Ni-2.5-2.8%Mo) had smallest degraded surfaces. No presence of Cl^- was observed on the surface of this cast steel, contrary to what happened to other examined alloys.

From the conducted research it follows that the material most recommended for operation in media containing Cl^- ions is 19Cr-11Ni-2Mo cast steel and two-phase ferritic-austenitic cast steel.

5. Conclusions

According to the criteria determined under item 4, the following conclusions can be formulated.

The heaviest weight losses suffered both cast iron grades. In the case of Cr-Ni cast steel, the weight losses were much more moderate. In two-phase ferritic-austenitic (F-A) cast steel, no changes in the original weight of samples were observed even after the longest time of 430 test hours.

Surface assessment of the examined iron alloys confirmed stronger surface degradation in both cast iron grades operating in the medium of mine water containing Cl^- ions and general corrosion on all surfaces. In the case of 18Cr-9Ni and 19Cr-11Ni-2Mo

cast steels, only local corrosion centres were observed.

As regards Cr-Ni cast steels, it seems advisable to prolong the stand tests to better examine the intensity of corrosion phenomena.

The proposed methodology enables comparative studies of different alloys operating under the corrosive-erosive conditions imitating the aggressive environments used in actual industrial practice.

Acknowledgements

The research part of the study has been partially executed under a Statutory work (AGH- UST) no. 11.11.170.318 Task no. 5.

REFERENCES

- [1] S. Płaza, L. Margielewski, G. Celichowski, *Wstęp do tribologii i trybochemia*, Wyd. Uniwersytet Łódzki, Łódź (2005).
- [2] G. R. Kingsbury, *Wear resistance of metals and alloys*, ASM Intern., Illinois, USA (1988).
- [3] J. Sadowski, *Nowa interpretacja i ocena zużycia tribologicznego*, Wyd. Politechnika Rzeszowska, Rzeszów (2006).
- [4] A.J. Sedriks, *Corrosion of stainless steel*, 2nd Ed., John Willey & Sons, New York, USA (1996).
- [5] CASTI Handbook of Stainless steel and nickel alloys, CASTI Publ., Edmonton, Canada (2001).
- [6] J. Głównia, D. Szczypkowski, B. Kalandyk, J. Górniok, S. Sobuła, Niskowęglowe staliwo ferrytyczno-austenityczne na odlewy pomp; *Przegląd Odlewnictwa* **58**, 12, 616-623 (2008).
- [7] Z. Stradomski, M. Soiński, J. Stradomska, D. Dyja, Znaczenie fazy σ w procesie zużycia erozyjnego staliwa typu duplex, *Archives of Foundry Engineering* **8**, 3, 141-144 (2008).
- [8] B. Kalandyk, M. Starowicz, Mechanical properties and corrosion behaviour of

- 18Cr-11Ni-2,5Mo cast steel, Archives of Foundry Engineering **9**, 4, 87-90 (2009).
- [9] B. K a l a n d y k, Wear resistance comparison of high alloyed Cr-Ni cast steel in the SiC and water abrasive slurry, Technologické Inžinierstvo **5**, 2, 48-50 (2008).
- [10] B. K a l a n d y k, Praca naukowo - badawcza "Badanie wpływu szybkości krzepnięcia odlewów o zróżnicowanej grubości ścianek na powstawanie faz kruchych w wysokostopowym staliwie Cr-Ni", Wyd. Odlewnictwa AGH (2009).
- [11] A. H a r a t, A. G r m e l a, Impact of mine water from The Upper Silesian Coal Basin areas on change quality of water in Olza river in years 2000-2007, Monitoring Środowiska Przyrodniczego **9**, 57-62 (2008).
- [12] H. K r a w i e c, V. V i g n a l, J. B a n a ś, Macroscopic and local electrochemical studies of austempered ductile iron in perchlorate solutions, Journal of The Electrochemical Society **153**, 7, B231-B237 (2006).
- [13] H. K r a w i e c, J. L e l i t o, E. T y r a ł a, J. B a n a ś, Relationship between microstructure and pitting corrosion of ADI in sodium chloride solution, J. Solid State Electrochem **13**, 935-942 (2009).