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THE SPREAD OF CORROSION IN CAST IRON AND ITS EFFECT ON THE LIFE CYCLE OF TRANSPORTATION VEHICLES

Tomáš Binar[1], Jiří Švarc[1], Petr Dostál[2], Michal Šustr[2], Jan Tippner[3]

[1]Department of Logistics, University of Defence, Brno, Kounicova 65, 662 10 Brno, Czech Republic
[2]Department of Technology and Automobile Transport, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic
[3]Department of Wood Science, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

Abstract

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This article deals with the spread of corrosion in material at different exposure times, and its effect on the measured brittle fracture and notch impact strength under different temperature conditions. To assess the degradational effect of corrosion on the material characteristics represented by the measured impact strength, we conducted a fractographic analysis of fracture surfaces, the aim of which was to evaluate the spread of corrosion in the material. In the first part of the experiment, two corrosion tests are simulated with a duration time of 432 and 648 hours, to compare the degradation effect of corrosion on the notch impact strength, depending on the duration of the corrosion tests. The following part shows the results of the impact bending test, where the experiment was conducted in an area of reduced and increased temperatures. The final part summarizes the results of the fractographic analysis of sample fracture surfaces from the impact bending tests. Based on the measured the length of the corrosion cracks, we analyzed the sample at the notch and from the material surface after the impact bending test.

Keywords: exposure time, notch impact strength, metallography, depth of corrosion cracks, fractographic analysis, life cycle, logistics support

INTRODUCTION

When assessing the life cycle of transportation vehicles, we dealt with the issue of the effect of the environment in which the structures are located and its impact on the reliability of mechanical components of which the vehicle consists (Dostál *et al.*, 2012; Roberge, 2008; Shastri, 2007). Machine failures may be caused by excessive operational load, a material defect, failure to comply with technological processes in production, or external influences affecting the machine component, which forms a functional unit (Scott, 2003; Davis, 2000; Roberge, 2008; Chamberlain and Trethewey, 1998; Ghali *et al.*, 2007; Ahmad, 2006). The durability of the vehicle is therefore influenced by a number of factors that may result in economic losses due to a fault (Dostál *et al.*, 20012). In most industrial companies dealing with machine production, inspections of machinery are conducted regularly to eliminate possible faults (Ghali *et al.*, 2007). In budget organizations, including the Army of the Czech Republic (ACR), funds are planned and allocated for each year, and they cannot be transferred to the following year. One of the primary tasks of the ACR in the field of logistics support is to maintain the operational reliability of military vehicles used in the Czech Republic and in foreign peacekeeping missions. Units and facilities that provide technology for foreign peacekeeping missions have a relatively large amount of military vehicles, which are stored in open military units all year round when they are not deployed abroad. When the vehicles stand in one place for a long time and are exposed to different climatic changes during the year, we can assume that corrosion

I: *Chemical composition of cast iron*

Chemical composition (in weight %)	C	Mn	Si	P	S	Cr	Ni	Cu
Specimens	2.870	0.794	1.453	0.292	0.055	0.082	0.050	0.147

will develop in certain materials of the vehicle (Chamberlain and Trethewey, 1998; Ghali, 2007). Corrosion as a degradation factor of the material may cause weight loss, which is accompanied by a change in the original size and a reduction in material characteristics, which is negatively reflected in the life cycle of the vehicles (Davis, 2000; Roberge, 2008). One possible method of analyzing and qualitatively measuring the effect of corrosion on the material is to measure the length of corrosion cracks based on the performed metallography (Scott, 2003; Davis, 2000; Roberge, 2008; Chamberlain and Trethewey, 1998; Ghali *et al.*, 2007; Ahmad, 2006).

MATERIALS AND METHODS

We used optical emission spectrometry on the examined samples to find the chemical composition of the material, which corresponds to cast iron according to EN 1561.

Before measuring the depth of corrosion cracks, the samples were inserted into a condensation chamber for an exposure time of 432 hours and 648 hours for simulated corrosion tests according to ČSN 03 8131 and ČSN 03 8205.

The effect of climatic conditions on the life cycle was evaluated through the degradation effect of the corrosion on the material, where different corrosion tests were simulated in the condensation chamber on the basis of which we can interpret the effect of corrosion on the equipment over a period of 3 and 5 years, when stored in an open area.

In order to assess the corrosive effect on the life cycle, we selected military truck TATRA 815, which is the most common type of military vehicle in the ACR. Test specimens for an impact bending tests were produced from the engine cylinder liner. In vehicles that are not used for long periods of time and are exposed to climatic changes, we can expect the development of corrosion in the area above the piston on the engine cylinder.

The first set of corrosion tests that were carried out according to ČSN 03 8131 a ČSN 03 8205 simulated the effects of corrosion on the material sample over a period of 432 hours, where one cycle (24 hours) is 8 hours in the chamber at 43 ± 2 °C and 100 % relative humidity, and 16 hours outside the test chamber at a temperature of 23 ± 2 °C and maximum 75 % relative humidity in a room with a clean atmosphere. This accelerated corrosion test simulated the effect of corrosion on the material of the test sample created from the engine cylinder liner of a military vehicle that was standing in the open area of a military unit for a period of 3 years.

The second set of corrosion tests was carried out according to the same standards, over a period of 648 hours. The tests simulated the effects of corrosion on the engine cylinder liner in vehicles that stand in the open area of a military unit for a period of 5 years.

After the fixed exposure time, the sets of samples were prepared for metallographic analysis, the aim of which was to determine the depth of the corrosion on the surface of the sample (Fig. 1a) and in the notch; we can expect the greatest effect of the exposure to the corrosion on the formation and length of corrosion cracks, due to cross-sectional weakening in the notch compared to the cross section of the sample (Fig. 1b).

Preparation of samples for evaluating the measurements of corrosion cracks consisted of pressing into plastic, grinding, polishing and etching with 2 % Nital, by means of which a microstructure was induced.

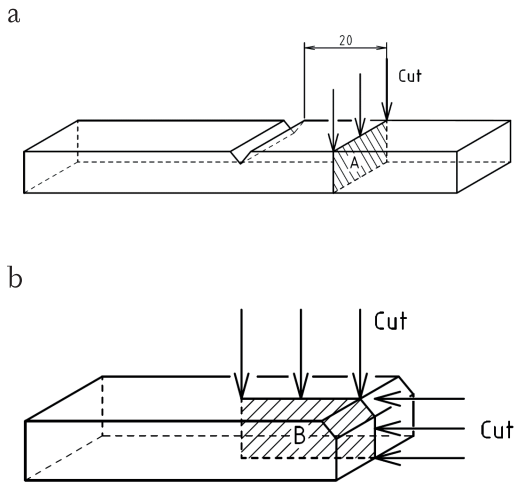
Preparation of samples

The material characteristic describing the brittle fracture behavior of the material of the engine cylinder liner, the notch impact strength (KCV), was determined on instrumental impact hammer RKP 450 iwi. The measurements were performed in the temperature range of –80 °C to +80 °C. The aim of the test was to determine the effect of corrosion on the KCV material characteristics. We can theoretically assume that the corrosive effect will initiate the brittle fracture, and will be the decisive factor affecting the durability of the mechanical part, the engine cylinder liner through the test sample. Part of the experiment was determining the so-called to determine the benchmark KCV values, we performed tests on samples without corrosion. The average benchmark KCV value was 47.4 $J.cm^{-2}$.

Fractographic analysis of fracture surfaces after the development of corrosion, and the performance of an impact bending test, were used to evaluate the spread of the corrosive effect in the area under the notch and in the notch, where we expected concentrated stress causing the degradation of the material and a reduction in material characteristics. The analysis of fracture surfaces was performed on scanning electron microscope VEGA II XMU (TESCAN).

RESULTS AND DISCUSSION

The degradation effect of corrosion after an exposure time of 432 hours on the notch impact strength is shown in Tab. II. The temperature field for lower and higher temperatures at which



1: *Corrosion attack depth from the surface/ b Corrosion attack depth in the notch section*

II: *Values of notch impact strength KCV [J.cm-2] at the testing temperature after the corrosion test, source: own*

	KCV [J.cm^{-2}]						
Test conditions	−80 °C	−40 °C	−20 °C	0 °C	+20 °C	+60 °C	+100 °C
432 hours	35.0	39.4	40.4	43.1	43.4	44.3	47.8
648 hours	37.1	39.0	40.5	39.9	42.1	45.7	47.6

the research was conducted is larger than realistic climatic conditions in the Czech Republic, but the authors wanted to get the greatest possible amount of qualitative results describing the brittle fracture behavior of the tested material. In the lower temperatures shown in Tab. II, from the test temperature of 0 °C, we can see a noticeable reduction due to the degradation effect of corrosion in comparison to the benchmark KCV value of 47.4 J.cm^{-2} (free of corrosion).

The determined KCV values for simulated corrosion tests with an exposure time of 649 hours showed a greater effect of corrosion on KCV values in the temperature range of 0 °C to −80 °C.

For the simulated corrosion tests with an exposure time of 432 hours, we analyzed the area around the notch (Fig. 2) and in the notch (Fig. 3) for the testing temperature of −80 °C. In these images there are noticeable areas A, B, C, D affected by corrosive degradation, which caused a significant reduction in the measured KCV values compared to other values of the determined characteristic.

Analyzed areas (E, F, G, H) of the fracture surface around the notch (Fig. 4) and (I, J) in the notch (Fig. 5) in simulated corrosion tests with an exposure time of 648 hours, showed relatively extensive corrosion, causing a decrease in KCV values compared to the benchmark value.

The morphology of the analyzed fracture surface in all the figures consists of black areas corresponding to particles of graphite flakes. We can also see smooth metal facets. The separation of material between graphite particles and the metal matrix occurred in these facets, and we can see an imprint of the graphite particles. We can also observe the area of the metal matrix fracture (Dostál and Communeu, 2014; Dostál *et al.*, 2011). The fracture morphology in all the examined samples consisted of brittle fracture. At higher temperatures, the metal matrix of the cast iron is less brittle, and it was observed that the fracture spreads through the weakest points of the material, spreading through graphite particles. More graphite particles could be seen on the fracture surface, and the fracture is more patterned in comparison to fractures that occurred at low temperatures (Kunz and Fintova, 2014; Kunz *et al.*, 2006).

Evaluation of the local depth of corrosion on the surface of the sample measured at a 20 mm distance from the notch (Fig. 1a).

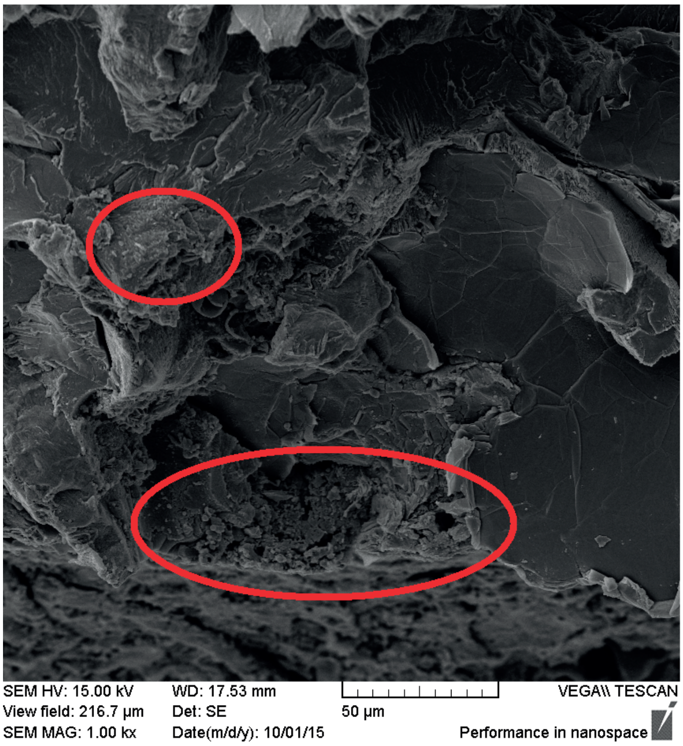
Tab. III shows the mean values of the depth of the corrosion on the surface and in the notch, depending on the exposure time of the corrosion test.

At the exposure time of 432 hours in the condensation chamber, we measured a mean depth of corrosion (length of corrosion cracks) from the surface in the range of 41 to 46 μm (Fig. 6 and Tab. III).

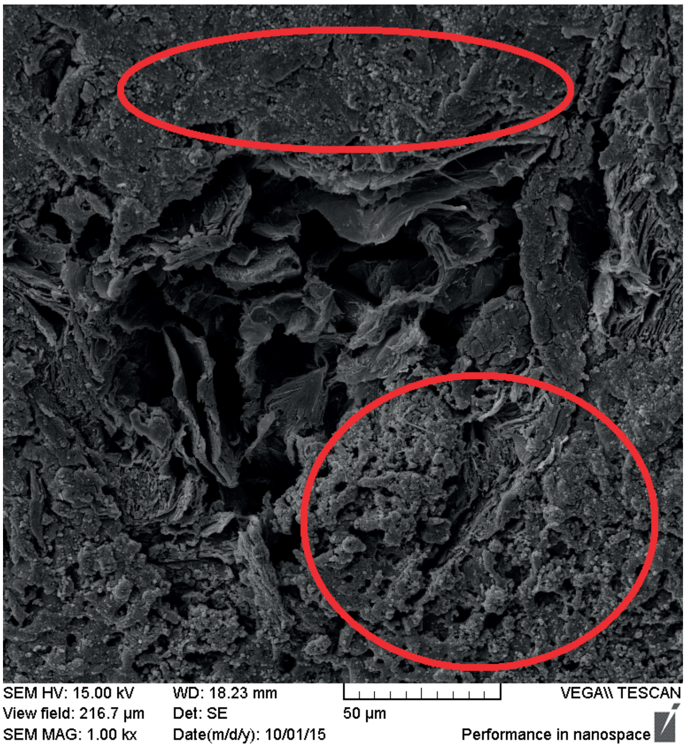
In test samples exposed to corrosive stress for a period of 648 hours, we measured the mean values of the depth of corrosion (length of corrosion cracks) from the surface in the range of 35 to 60 μm, and it was shown that the depth of corrosion cracks increases with the longer exposure time (Fig. 7 and Tab. III).

Tab. III shows the mean values of the local depth of corrosion (length of corrosion cracks) in the notch, after an exposure time of 432 hours. The mean values were in the range of 10 to 28 µm.

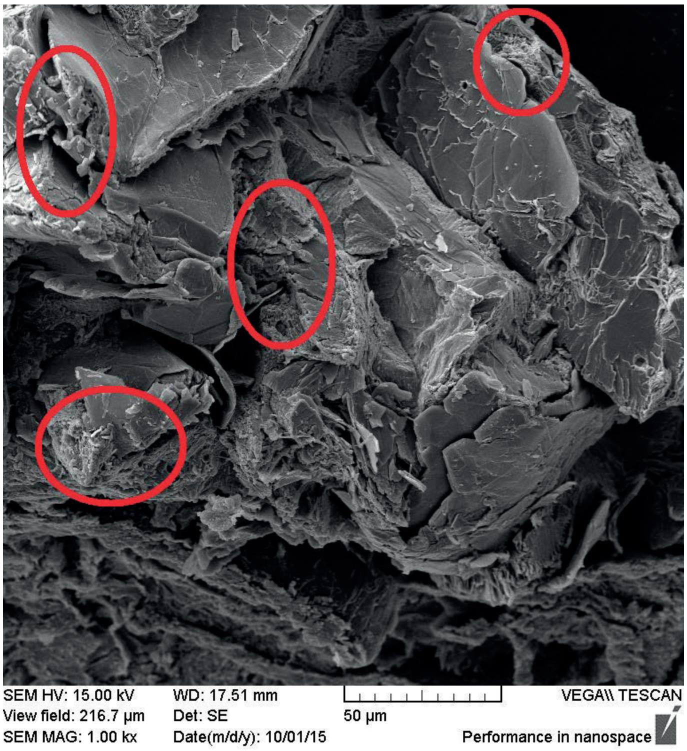
After an exposure time of 648 hours in the condensation chamber, the mean corrosion depth value (length of corrosion crack) measured in the notch of the samples was in the range of approx. 20 to 38 µm (Tab. III).



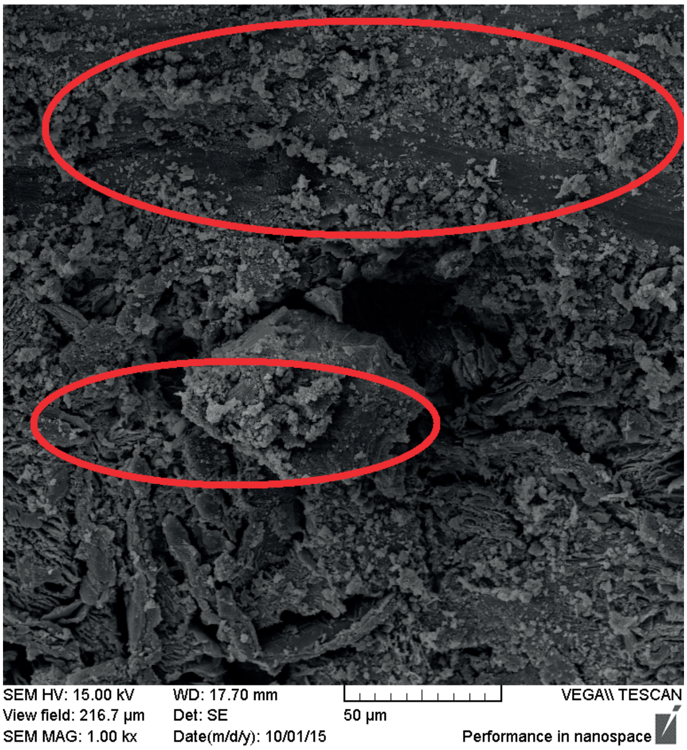
2: *Fractographic analysis Sample 1, 432 hours, area under the notch*



3: *Fractographic analysis Sample 1, 432 hours, area in the notch*



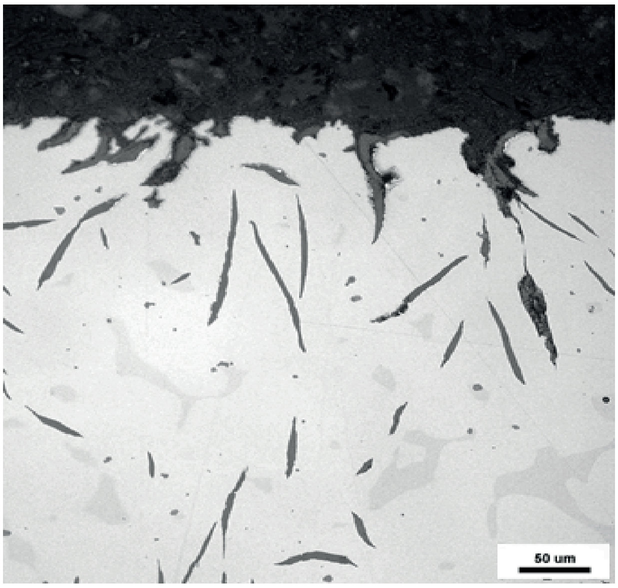
4: *Fractographic analysis Sample 2, 648 hours, area under the notch*



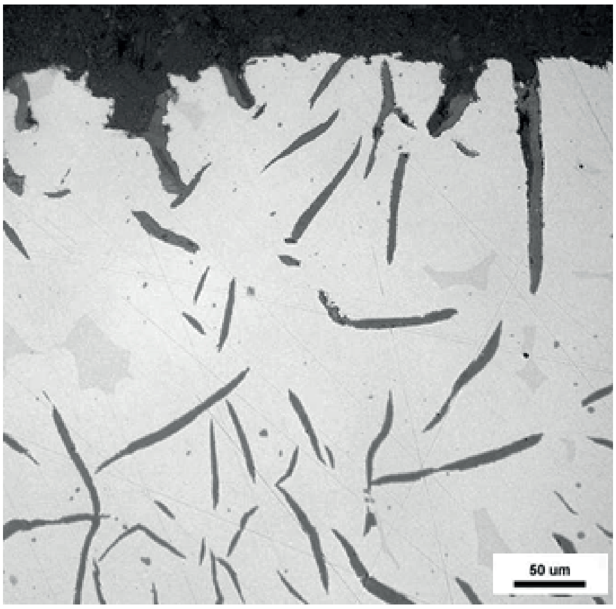
5: *Fractographic analysis Sample 2, 648 hours, area in the notch*

III: *Chemical composition of cast iron*

	Exposure time in hours [hr.]	
	436	**648**
Mean values from the surface [μm]	41.6	35.6
	41.8	45.5
	42.6	54.5
	45.5	54.7
	46.5	60.4
Mean values in the notch [μm]	10.3	20.4
	12.7	25.3
	26.3	26.3
	26.5	33.1
	28.2	38.1



6: *Metallography of the sample after the exposure time of 432 hours from the surface*



7: *Metallography of the sample after the exposure time of 648 hours from the surface*

CONCLUSION

Laboratory tests performed after the simulated corrosion tests for a period of 432 and 648 hours to determine the KCV brittle fracture characteristic, demonstrated a degradation effect of corrosion, which resulted in a reduction in the fixed material KCV characteristic. The boundary test temperature can be described as the temperature at which the determined characteristic is reduced in both simulated corrosion tests after the development of corrosion, at 0 °C and lower. In military vehicles exposed year-round to different climate changes, we can expect the development and degradation effect of corrosion in the engine cylinder liner, which will ultimately lead to a boundary condition with irreversible damage, requiring the repair of the affected part.

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Contact information

Tomáš Binar: tomas.binar@unob.cz
Jiří Švarc: jiri.svarc2@unob.cz
Petr Dostál: petr.dostal@mendelu.cz
Michal Šustr: michal.sustr@mendelu.cz
Jan Tippner: jan.tippner@mendelu.cz