Testing of conservation means for steam engines as a part of industrial cultural heritage

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Summary

The Cultural Industrial Heritage includes machinery equipments, such as steam and electrified piston compressors, turbo compressors, electrical convertors and other equipments with an extraordinary historical value preserved in original state including the craftsmen details (e.g. door fittings, paving, lining, glass and brass lubricators, name plates). These machineries are assembled from many metallic materials – cast iron, steel, brass, etc. and some parts are painted. At present they are in exposition in buildings – former engine rooms - with uncontrolled conditions.

Key words: industrial culture heritage, material degradation, corrosion protection, air pollution, temporary protection

1 Introduction

As a result of the industrial revolution and rapid economic progress over the 19th and 20th centuries, Europe has a rich industrial culture heritage which represent many different sites such as mines and steel works, the energy sector - power stations, warehouses, mining equipment and machinery, geometers, the chemical industry, water-supply and the transport systems made by metallic materials. Integral parts of industrial heritage are various machines and other equipments such as communication, laboratory, measuring tools, etc.. These machines and equipments are usually exhibit in non-heated, not air-conditioned spaces (industrial historical buildings) – Figure 1.

The majority of machine frames are made by cast iron which has good resistance to corrosion due to the microstructure component compounds – graphite and phosphite eutectic - and the tough surface skin formed as the castings cooled. Cast iron corrosion tends to flake and crumble - this phenomenon is evident on machine frames (Fig. 2).

The machines are usually exposed for 50 to 100 years, but for the majority of this exposure the surface was protected by different paints. The coating layer thickness of machines is very different on each part – they vary from 50 µm to 1000 µm with average value ca 400 µm. There were found similar failures of paint layers – rusting, cracking, flaking and peeling off (Fig. 3).

Figure 1: Mining museum engine buildings and equipments

Figure 2: Example of cast iron flaking on machine frames

As the indoor environments of non air-conditioned engine houses have high relative humidity, the very specific damage was found – blistering (Fig. 3e). Many engine houses have large windows so in the summer season the side of machines' surface oriented to the south is exposed to high temperature and degradation. On these surfaces the paint deterioration in the form of mud cracking was found (Fig. 3f). All forms of paint failure lead to corrosion attack of iron/steel substrate.

Copper and copper alloys, mainly bronze, was used for springs, bearings, bushings, automobile transmission pilot bearings, and similar fittings, and is particularly common in the bearings of small electric motors. As a part of various machines, they had been treated by oil or grease used for lubrication of machines. There was not found any significant corrosion damage of these elements.

The thick residual layers of greases and oils should give a barrier protection but on the other hand they increased the corrosion attack of materials (Fig. 4), because during degradation their acidity increased and they also absorbed some air moisture. These films may also cumulate solid particles with different chemical properties (e.g. carbon particles) which may increase the corrosion damage.

The conservation of all metallic surface of machinery exposed in engine houses of Czech mining museums is done by various types of oils and waxes, in some cases not suitable for temporary corrosion protection. Commercially available oils and/or waxes used for temporary corrosion protection contain significant amount of corrosion inhibitors.

2 Atmospheric corrosivity of indoor exhibition rooms

Atmospheric corrosion of metals and deterioration of protective coatings is a serious problem for the protection of industrial cultural heritage. In atmospheric environments, metallic materials are damaged by basic climatic factors such as temperature and relative humidity.

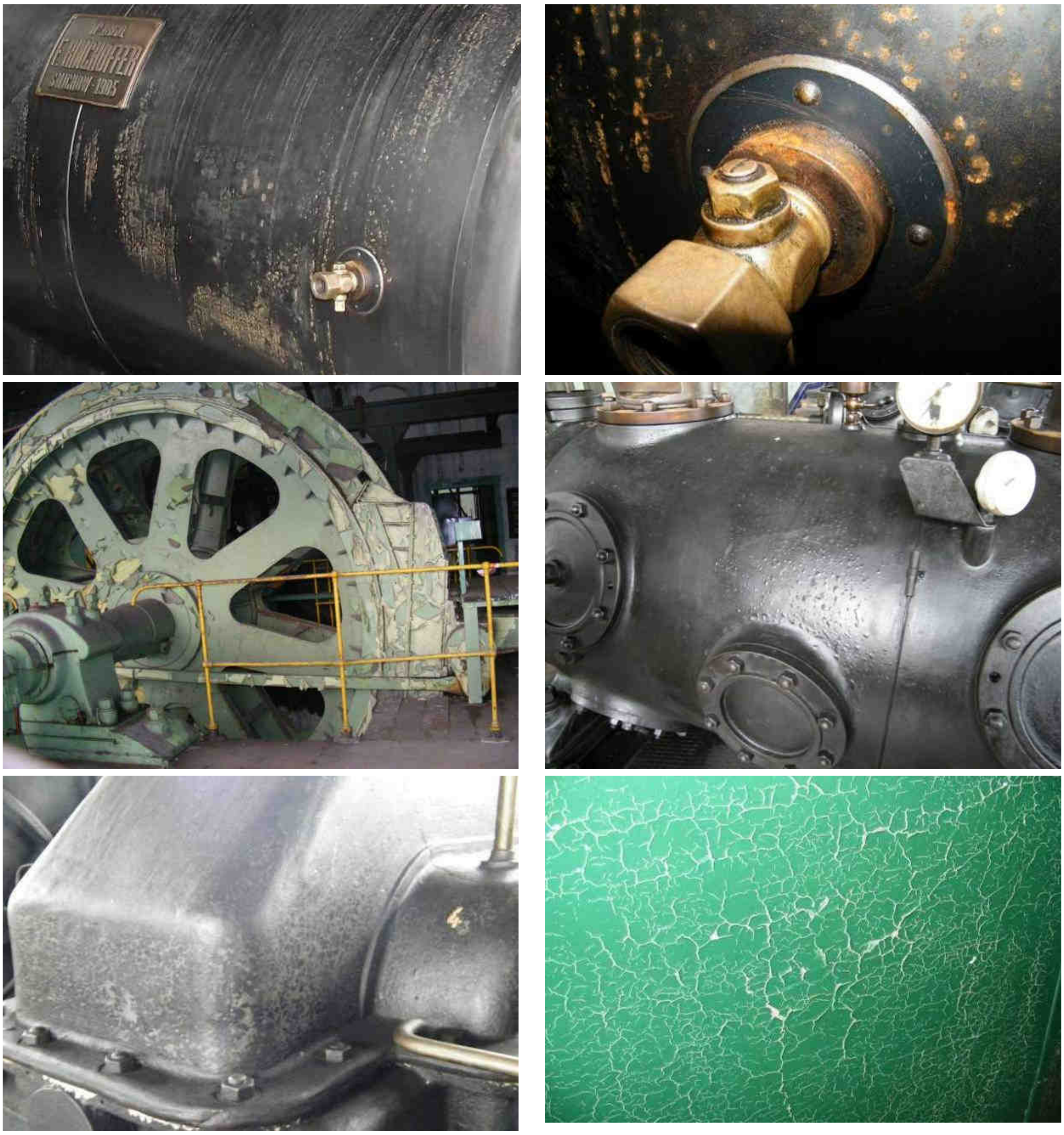


Figure 3: Deterioration of paint system on machines

Figure 4: Examples of residual oils and greases on steam engine parts

At operating conditions the indoor climate at engine houses was relative warm and without humidity and the regular maintenance – painting, greasing, oiling – had been applied. At present they are in exposition in buildings without heating or other air conditioning. The degradation of materials at indoor atmosphere increases with higher humidity and the kind and level of pollution, too. Due to variations of outdoor humidity and temperature uncontrolled indoor microclimate initiates corrosion within former industrial plants/buildings (Fig. 5). Indoor atmospheres of buildings of industrial culture heritage are polluted mainly by components from external sources. The indoor sources are practically negligible.

E.g. in 2008-11 the climatic parameters were measured in three localities of mining open air museums – Pribram, Vinarice and Ostrava, Czech Republic – outdoor and indoor in uncotrolled space where the large steam engines are placed. The evaluation of indoor atmosphere can be done by direct determination of corrosion attack of carbon steel reference metal after an exposure for one year according to ISO 11844 *Corrosion of metals and alloys — Classification of low corrosivity of indoor atmospheres* – Table 1. According the r_{corr} the corrosivity of exhibiting space varies from IC2 (Vinarice, 1st floor) to IC3 (Pribram, Vinarice – basement) and even up to IC4 (Ostrava).

The protective efficiency of various temporary conservation means was tested in these exhibiting rooms too.

Table 1: Climatic parameters in mining open air museums – yearly average values and carbon steel coupon corrosion loss

locality	space	temperature (°C)	relative humidity (%)	TOW (hrs.a^{-1})	SO_2 (µg.m^{-3})	corrosion loss (g.m^{-2})
Pribram	outdoor	7,3	79,0	3995	6,5	42,2
	indoor, 1st floor	10,6	72,2	3224	2,6	1,5
Vinarice	outdoor	8,6	79,0	4210	6,8	38,2
	indoor, 1st floor	8,6	72,8	1851	2,7	0,5
	indoor, basement	7,0	79,0	4159	2,7	2,8
Ostrava	outdoor	9,8	80,0	4610	7,6	146,3
	indoor, 1st floor	10,0	72,0	1848	3,1	15,1

NOTE: SO_2 concentration in indoor spaces was not measured but estimated as ca 40% of outdoor concentration according to IMPACT pollution model assumes that outdoor pollutants, as trace gases in the air, enter a building through the ventilation system and by infiltration through cracks, crevices, window openings. The measurement realised in 80ties in the Czech Republic showed that the decreasing of SO_2 in building indoor is higher (90 µg.m^{-3} outdoor and 11 µg.m^{-3} indoor).

Figure 5: Example of steam engine before and after conservation
(1 year left without regular maintenance)

3 Tests of temporary protective means

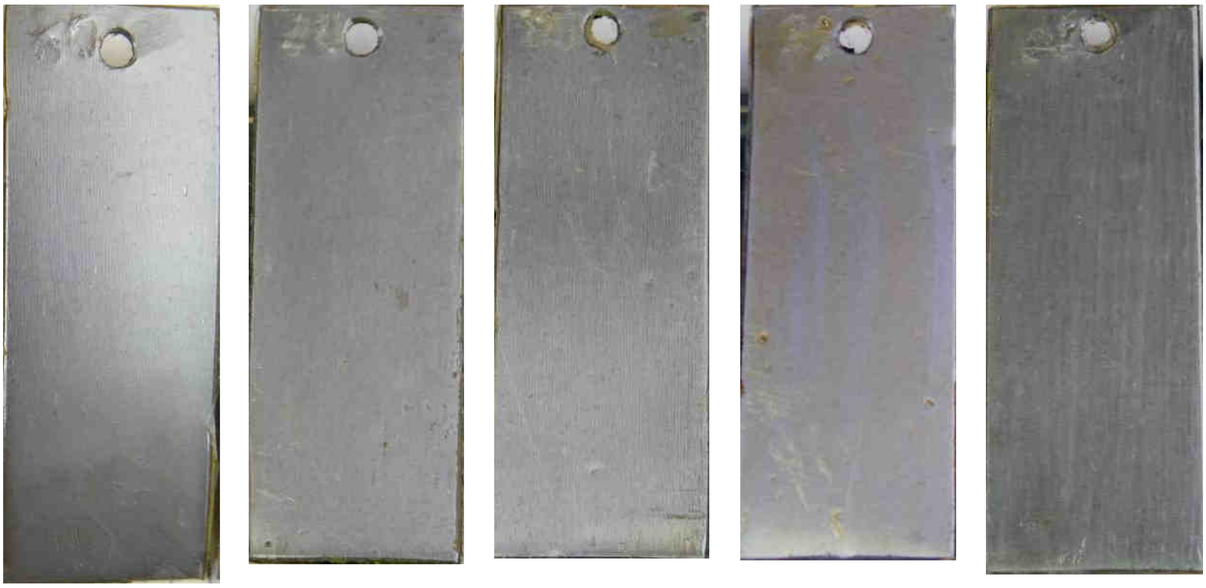
Protective effect of temporary protective means is given by barrier of layer + corrosion inhibitors. In the indoor exposure condition where the film is not exposed to intensive condensation the barrier efficiency depends on the thickness of layers, or area mass of layer respectively.

From wide range of temporary corrosion protective oils and similar products available on the market the 5 of them had been chosen for testing in laboratory and field exposures. Protective oils are available in a wide variety of viscosity ranges and are designed to leave an oily soft film on surfaces, in some cases partly dry film. The selection of them was done on the environmental parameters of exposure spaces and the aesthetic requirements for protected surfaces. The time of durability of them is minimum 1 year because in this period the re-conservation is usually applied in the mining museums. The basic characteristics of tested temporary means are given in Table 2.

Table 2: Tested temporary corrosion protective products

products	film forming agents	area mass of layer ($g.m^{-2}$)	character of film
1	oil	6,82	oil film
2	inhibitor solution	4,04	dry film
3	oil	21,69	oil film
4	oil	24,22	dry film
5	microcrystalline wax	14,17	dry film

The tested products are applied on the carbon steel coupons (Fig. 6) and the area mass of layers was estimated. The coupons had been placed in the mining museums´ engine houses near to various machines (Fig. 7) together with dataloger for climate data measuring (see Table 1). These field exposures had been performed for 1 year period in all mining museums.



1 2 3 4 5

Figure 6: Coupons with layer of tested temporary protective means

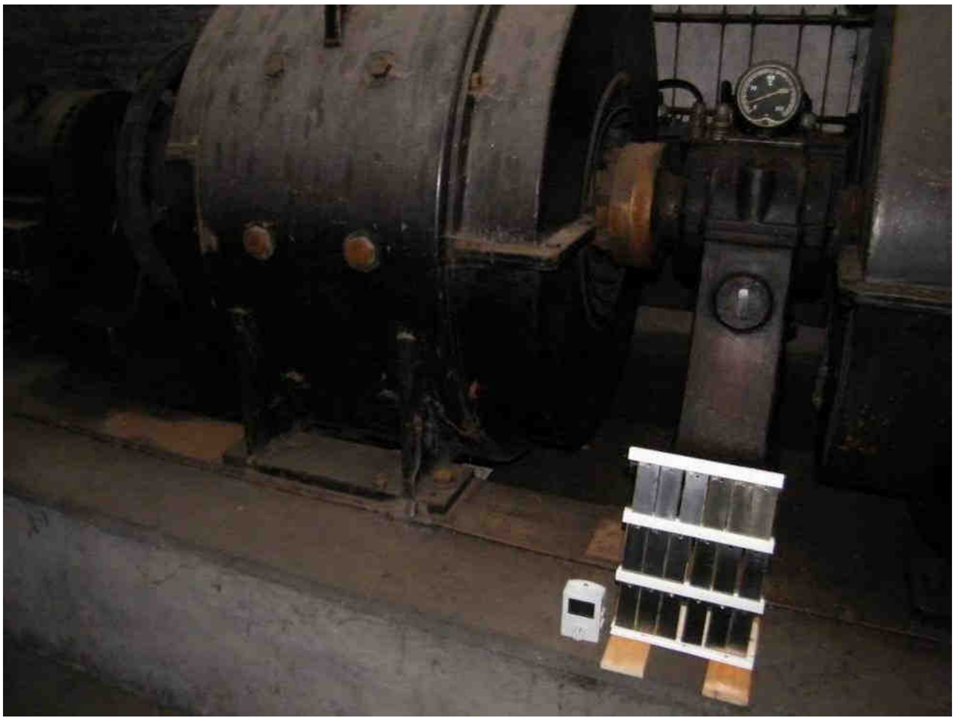


Figure 7: Example of coupons´ exposure and climatic data measuring

One set of coupons was tested by accelerated cyclic laboratory test in the condensation chamber according to Czech standard CSN 03 8205 *Corrosion protection. General requirements to temporary protection of metals* at conditions:

- 8 hrs – permanent water condensation, temperature 40 ± 2^{0}C and 100% relative humidity,
- 16 hrs - temperature 20 ± 5^{0}C and max. 75% relative humidity.

After exposure the coupons was visually evaluated. On some coupons the filliform corrosion was found (Fig. 8) which is characteristics for corrosion of carbon steel under the layer of organic films. The results are given in Table 3. The corrosion loss was estimated after removal of protective film and corrosion product layers and the protective efficiency of tested temporary protective means calculated from the equation:

$$U_r = \frac{K_o - K_p}{K_o} \cdot 100,$$

where U_r is relative protective efficiency in %,

K_o is corrosion loss of coupons without film of protective mean in g.m^{-2},

K_p is corrosion loss of coupons with film of protective mean in g.m^{-2}.

Table 3: Results of field tests

products	coupons´ corrosion loss (g.m^{-2})				U_r (%)
	shaft Michal	shaft Mayrau	shaft Robert	shaft Vojtech	
1	0,39	0,24	0,18	0,25	81
2	0,50	0,00	0,24	0,30	78
3	0,72	0,31	0,31	0,41	96
4	0,67	0,29	0,11	0,35	75
5	0,56	0,17	0,06	0,21	87

Figure 8: Examples of filliform corrosion on coupons

The results of accelerated test are given in Table 4 as a corrosion loss and the protective efficiency of tested temporary protective means. In the field test the highest corrosion loss of coupons protected by tested temporary means had been found in the shaft Michal, Ostrava where the highest corrosivity of exhibiting space was estimated, too.

Table 4: Results of accelerated laboratory test

products	corrosion loss ($g.m^{-2}$)	U_r (%)
1	26,5	42
2	12,7	72
3	0,7	99
4	1,9	96
5	9,3	80

Conclusion

The results from the field and accelerated laboratory tests are slightly different so the choice of temporary corrosion protective means for such specific application as the corrosion protection of machines in the non heated engine houses of mining museum must be done on the basis of field test. In this type of accelerated laboratory test the barrier protective efficiency depend on emulsification of oil/wax layers. The lower U_r was estimated for temporary protective means which formed the thinner film.

To modelling the real exposure conditions may be done by less severe laboratory tests, e.g. test in climate chamber without water condensation but the obtaining some results takes very long so the field test are most simple and representative for this reason.

As the surfaces of these equipments are covered by various paints it is necessary to verify the compatibility of both layers.

On the results of this study the conservation of engines in mining museum Vinarice had been done.