DOI: 10.37105/enex.2020.1.1.01

ENGINEERING EXPERT
RZECZOZNAWCA

Determining the technical condition of steel flue gas conduit shafts' hot-dip galvanisation, illustrated with the example of chimney stacks at the 'CZAJKA' sewage treatment plant in Warsaw

Leopold KRUSZKA [1] (*ORCID ID: 0000-0001-5129-2531*)
Andrzej OLAS
Kamil SOBCZYK [1] (*ORCID ID: 0000-0002-5929-757X*)
[1] Military Univ. of Technology, Dept. of Military Engineering and Military Infrastructure, 2 Kaliski Str., 00-908 Warsaw, Poland
corresponding author: kamil.sobczyk@wat.edu.pl

Abstract: The paper focuses on analysing the technical condition of steel flue gas conduit shafts' hot-dip galvanisation in chimney stacks operating in a corrosive air environment at the 'Czajka' sewage treatment plant in Warsaw according to the 2010 actual state. It presents an assessment of the quality of the zinc coating based on facts revealed during an on-site inspection and indicates a cause-and-effect relationship for the discovered defects. An assessment of the quality of steel used for the load bearing shafts was also carried out within the scope of the paper on the basis of samples tested using a Foundry-Master spectrometer. Consequently, remedial action for the identified defects has been proposed.

Keywords: hot-dip galvanisation, chimney, Sandelin effect.

Please, quote this article as follows:

Kruszka et al., Determining the technical condition of steel flue gas conduit shafts' hot-dip galvanisation, illustrated with the example of chimney stacks at the 'CZAJKA' sewage treatment plant in Warsaw, Engineering Expert, pp. 1-7, No. 1, 2020, DOI: 10.37105/enex.2020.1.1.01

1. Introduction

Today, a lot of attention is paid to maintaining the technical condition of structures that are particularly important in people's everyday lives. Correct management and necessary inspections during the period when a given structure is in use play a key role in its life-cycle [1–4]. If damage to elements forming part of the structure in question occurs or if there is a suspicion that it has occurred, a structural survey detailing the technical condition should be carried out in order to determine the nature of the problem, to have a ready to use repair procedure at hand, and to minimise possible negative consequences. Power plants, water intake stations, telephone exchanges, natural gas pumping stations or sewage treatment plants (e.g. the 'Czajka' Sewage Treatment Plant in Warsaw) are just some of such non-military key infrastructure facilities [5].

The aim of this paper is to determine and analyse the technical condition of steel flue gas conduit shafts' hot-dip galvanisation in chimney stacks at the 'Czajka' Sewage Treatment Plant in Warsaw according to the 2010 actual state, and in particular to assess the quality of the zinc coating and the quality of steel used for the load bearing shafts operating in a corrosive air environment, on the basis of photographic documentation, a structural survey [6] and an on-site inspection report.

2. Flue gas conduit shaft specification

The steel assembly of the chimney stack's load bearing shaft, together with flue gas pipes, is 28 [m] tall. The external diameter of the load bearing shaft equals 813 [mm] and its walls are 8 [mm] thick. Two flue gas pipes are attached to a single load bearing shaft. Two identical units for discharging flue gasses have been designed and built. This arrangement means it is possible to discharge flue gasses from four power generators. The load bearing shafts stand on reinforced concrete hollow foundation boxes joined together to ensure sufficient spatial rigidity. Appropriate girder anchors were used within the scope of the building, making it possible to eliminate vibrations propagated from the load bearing shaft by making use of the weight of the walls. The steel assembly of the chimney stack's load bearing shaft, together with flue gas pipes, is shown in Fig. 1 a-c.

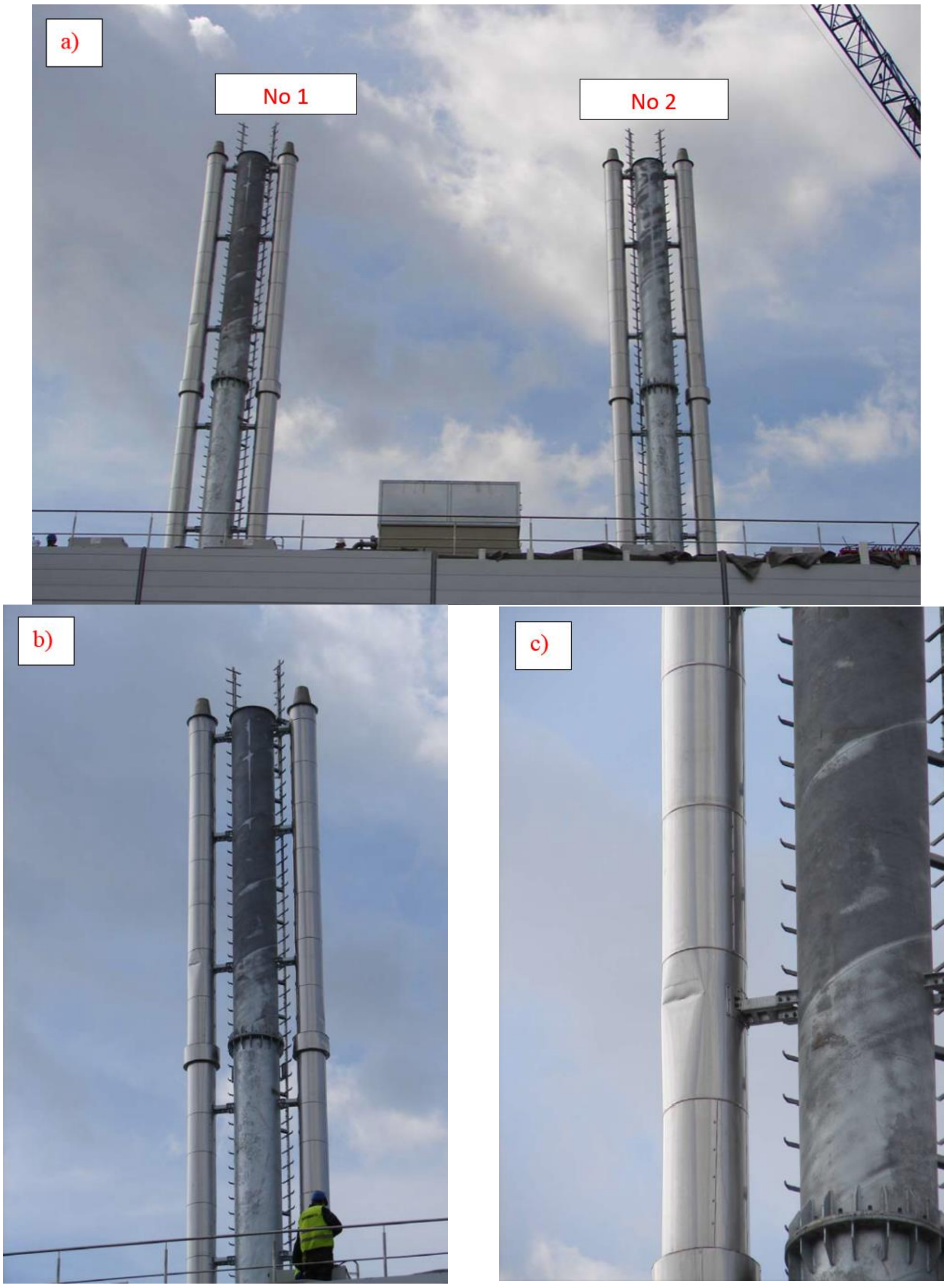

Fig. 1 a-c. Steel assembly of the chimney stack's load bearing shaft, together with flue gas pipes.

3. Assessment of the zinc coating

High degree of corrosion to the sub-coating material is a symptom indicating that the zinc coating is in a poor condition. See Fig. 2 for a fragment of the load bearing shaft's surface. Oxidation has set in to the sub-coating material as a result of atmospheric oxygen ingression under the zinc coating – iron oxides have developed in the form of brown deposits and these in turn have caused the coating to flake. The corrosion is uniform and does not weaken the material.

Fig. 2. Surface oxidation of the material under the coating as a result of zinc coating flaking off (marked in red).

Fig. 3 shows a badly chosen chamfering angle for a profile edge, which caused uneven application of the zinc coating. As a result, the thickness of the zinc coating in this area is less than that on a smooth surface and as such it suffered damage. This resulted in the coating flaking off and subsequent corrosion appearing on the original material's surface in the form of iron oxides.

Fig. 3. Appearance of corrosion in the form of oxidation on a profile edge (marked in red).

Zinc coating defects shown in Figures 2, 4 a-d and 5 a-b have been caused by the Sandelin effect. The phenomenon is caused by incorrect silicon content in the structure of the sub-coating material. The flaking zinc coating shown in Fig. 4 a-d is caused by non-uniform silicon content in the steel or by the so called scaling effect of rolled surfaces. The scaling phenomenon results from rolling defects. A small quantity of zinc penetrates under a flaking part of the original material. Secondary Fe-Zn phase crystallisation results in the coating flaking off.

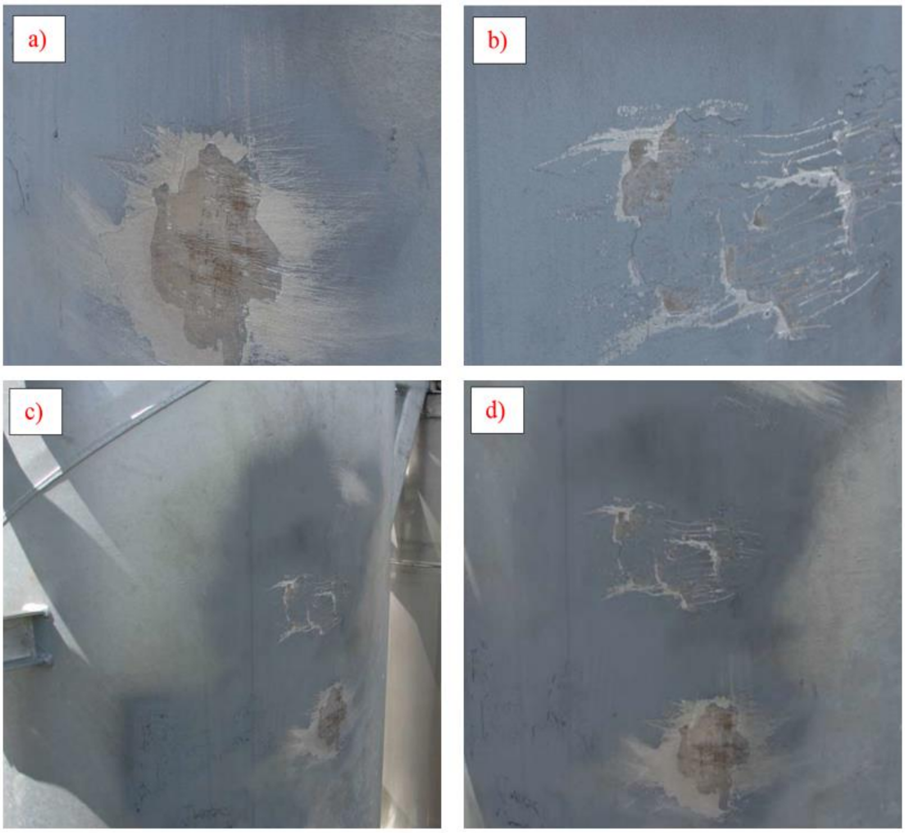

Fig. 4 a-d. Loss of surface zinc coating as a result of local Sandelin effect.

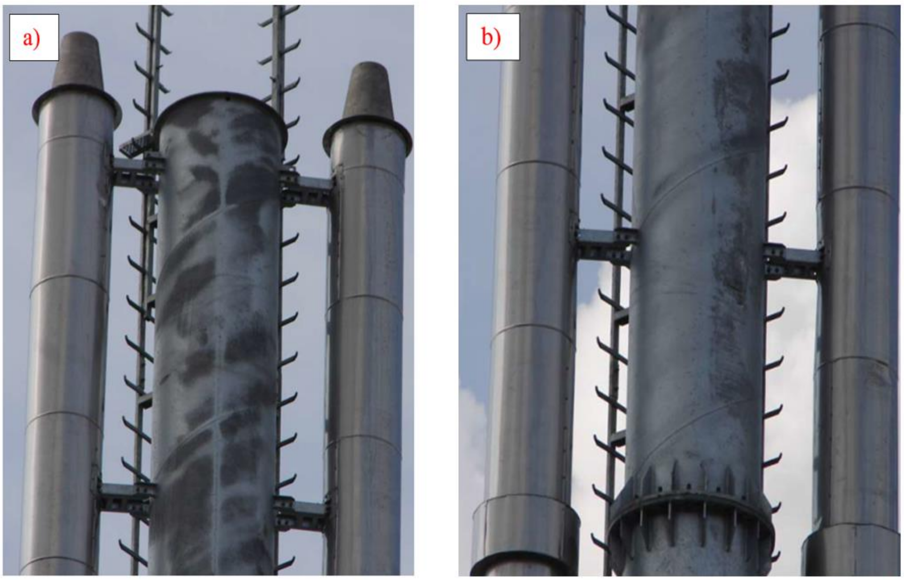

Fig. 5 a-b. Changing colour of the load bearing shaft as a result of the Sandelin effect.

The impact of silicon content on the thickness of the zinc coating is illustrated by a Sandelin diagram in Fig. 6. The graph shows that the Sandelin effect occurs for silicon content of 0.03%–0.1% and above 0.3%. With silicon-containing steel, there is a risk that the iron-zinc reaction will be particularly powerful and that the proportion of iron-zinc alloy in the zinc coating will be higher than normal. In extreme cases, the zinc coating may be made up of an iron-zinc alloy [7–8].

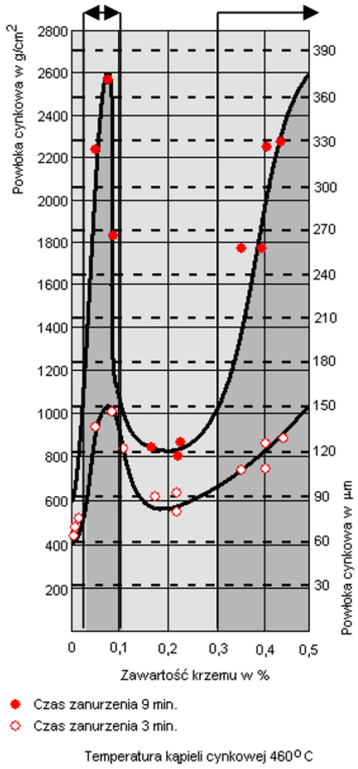

Fig. 6. A Sandelin diagram depicting the impact of silicon content on zinc coating thickness [8].

Corrosion typical for a zinc coating is shown in Fig. 7. It is a type of selective corrosion that only affects the hard zinc particles in the coating. This is due to the presence of hard zinc in the zinc bath. Hard zinc particles should be regularly removed from the zinc bath. Otherwise, they form deposits on the surface of the coating and come into contact with atmospheric oxygen [7].

A separate instance of 'white rust' is caused by improper storage of elements immediately after applying the zinc coating. Elements should be stored in such a way as to allow for sufficient air circulation between them until a protective layer develops on the surface in the form of zinc carbonate patina [9].

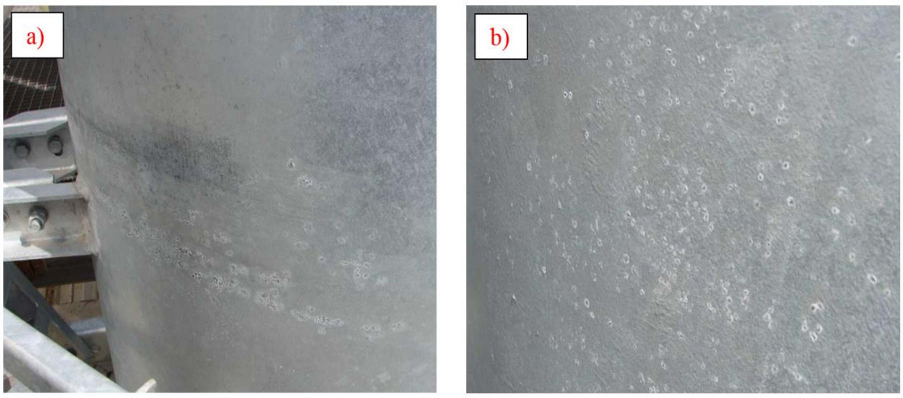

Fig. 7. 'White rust' on the surface of zinc coating.

4. An assessment of the quality of steel used for the load bearing shafts

In order to determine the quality of steel and the content of individual alloying components, a spectral analysis of samples cut from the load bearing shafts was carried out (samples shown in Fig. 8). In order to determine the content of alloying components, the tested samples were subjected to destructive tests in the form of partial melting by a measuring electrode on a Foundry-Master spectrometer (Fig. 9). Test results are shown in Table 1.

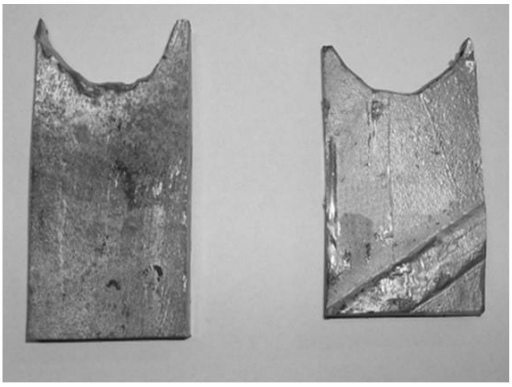

Fig. 8. Samples cut off from chimney shafts.

Fig. 9. Foundry-Master spectrometer.

Table 1. Chemical composition of steel used for chimney load bearing shafts.

Alloying element	Sample 1	Sample 2
C [%]	0.17	0.12
Si [%]	0.19	0.20
Mn [%]	0.60	0.40
P [%]	0.013	0.012
Cr [%]	0.036	0.030
Mo [%]	0.017	0.012
Ni [%]	0.074	0.061
Al [%]	0.035	0.025
Cu [%]	0.070	0.045

The data yielded by the analysis allows one to conclude that ordinary structural St3S grade steel was used for the chimney load bearing shafts. Such steel, unlike higher quality structural steel, has wide alloying element content limits. The silicon level content determined by the analysis of samples collected at two locations from the shaft does not indicate the occurrence of the Sandelin effect. The homogeneity of alloying elements in St3S grade steel is not observed as rigorously as for higher quality steel, hence their content varies across different areas of the chimney shafts and the Sandelin effect occurs locally.

5. Conclusions

The analysis of the technical condition of steel flue gas conduit shafts' hot-dip galvanisation in chimney stacks at the 'Czajka' sewage treatment plant in Warsaw according to the 2010 actual state discovered symptoms of accelerated wear and tear to the protective coating. The zinc coating does not comply with the PN-EN ISO 1461 and PN-EN ISO 14713 standards. The chemical composition of the steel used for the load-bearing shafts is not uniform throughout the structure. This causes local occurrence of the Sandelin effect (different zinc content) in the form of discolouration and roughness in the coating. Additionally, there are local blisters on the zinc coating, with rust spots appearing on the steel underneath. Localised corrosion is also to be found on the edges of the metal plates and connecting rings, which is indicative of an incorrect chamfer angle used for those elements. These phenomena result from incorrect preparation of the shaft surface layer before galvanising (shot blasting or peening) and insufficient protection of the surface of the zinc coating (immediately after application) against water and humidity.

In this case the repair procedure consists in:
- chamfering sharp edges of steel elements;
- re-galvanising the steel structure;
- ensuring the re-galvanised steel structure is correctly protected against water and humidity.

Acknowledgments

The authors would like to thank Marcin Sokolnicki for his assistance in the analysis and assessment of the processes taking place in flue gas conduit shafts.

Bibliography

[1] Frangopol, D., Kim, S. (2019). 'Inspection and Monitoring in Life-Cycle Analysis'. Life-Cycle of Structures Under Uncertainty. DOI: 10.1201/9780429053283-2.

[2] Brito, J., Silva, A. (2020). 'Life Cycle Prediction and Maintenance of Buildings'. Buildings, Vol. 10(6):112. DOI: 10.3390/buildings10060112.

[3] Lu, K., Jiang, X., Yu, J., Tam, V.W.Y., Skitmore, M. (2020). 'Integration of Life Cycle Assessment and Life Cycle Cost using Building Information Modeling: A Critical Review'. Journal of Cleaner Production. DOI: 10.1016/j.jclepro.2020.125438.

[4] Nowogońska, B. (2016). 'The Life Cycle of a Building as a Technical Object'. Periodica Polytechnica Civil Engineering, Vol. 60(3). DOI: 10.3311/PPci.7932.

[5] Sobczyk, K., Chmielewski, R., Duda, K. (2018). 'The concept of a prefabricated structure for protection of critical infrastructure facilities'. Biuletyn WAT, Vol. LXVII(2):133–143. DOI: 10.5604/01.3001.0012.0979.

[6] Łowkis, M. (2010). 'Ekspertyza budowlana dotycząca stanu technicznego wykonania ocynkowania ogniowego stalowych trzonów nośnych dla przewodów odprowadzenia spalin w Oczyszczalni ścieków Czajka w Warszawie'.

[7] Kania, H., Liberecki, P., Podolski, P., Tatarek, A. (2007). 'Przyczyny powstawania wad powierzchniowych powłoki cynkowej na rurach stalowych'. Hutnik – Wiadomości Hutnicze, Vol. 74(5):274–278.

[8] http://silesiametal.pl/wp-content/uploads/2019/08/EFEKT-SANDELINA.pdf.

[9] PN-EN ISO 14713-2. Powłoki cynkowe – Wytyczne i zalecenia dotyczące ochrony przed korozją konstrukcji z żeliwa i stali – Część 2: Cynkowanie zanurzeniowe.