INFLUENCE OF THE ZINC GALVANIZING ON FASTENERS CRACKING

SZŁAPA Ilona[1,2], JĘDRZEJCZYK Dariusz [2], SKOTNICKI Wojciech [2]

[1]F.Ś. BISPOL S.A. Bielsko-Biała, Poland, EU, iszlapa@bispol.com.pl
[2]University of Bielsko-Biala, Poland, EU, djedrzejczyk@ath.bielsko.pl; wskotnicki@ath.bielsko.pl

Abstract

In the paper reasons of damage of zinc galvanized screws M12x130 grade 12.9 were analysed. Examinations concerned analysis of fractures created as a result of screws cracking, the verification of structure correctness achieved after the heat treatment, hardness measurement at the screws cross section as well as inspections of the hydrogen content. Based on conducted examinations it was stated that the main reason of analysed screws cracking was steel hydriding - hydrogen brittleness which could take place on individual stages of the production process. Measured hydrogen content much more exceeds the acceptable values, and observed fractures are characteristic of brittle cracking.

Keywords: Zinc coatings, galvanizing, hydrogen brittleness, brittle cracking

1. INTRUDUCTION

In spite of the significant and systematic development of the technology, the corrosion processes are still the substantial problem also with the reference to steel constructions lifetime and are causing multimillion losses per annum [1]. Amongst applied methods of zinc coating the most often four processes are proposed: hot-dip galvanizing, galvanic zinc coating, sherardizing and lamellar technique. Every of applied methods reveals both advantages and disadvantages, and application of the specific method depends among others on the: working environment, the required corrosion resistance, the resistance to mechanical damages, or also aesthetics or the price [2, 3, 4]. The main purpose of anticorrosion zinc coatings application is to protect the construction elements against the loss of required mechanical properties during its operation.

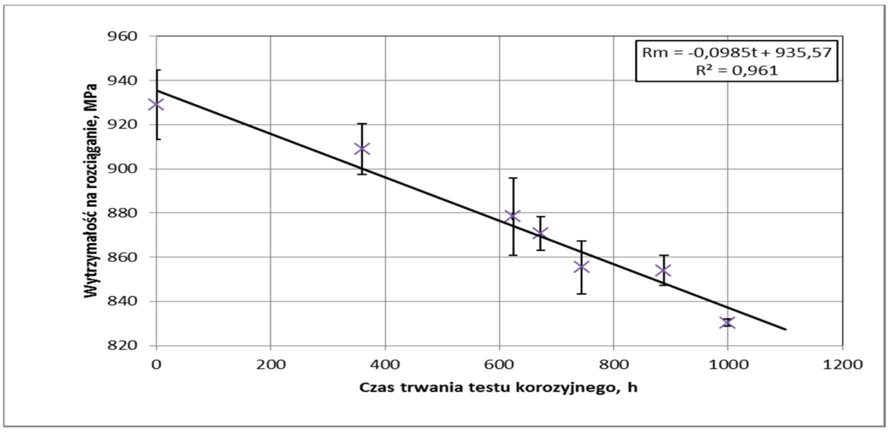
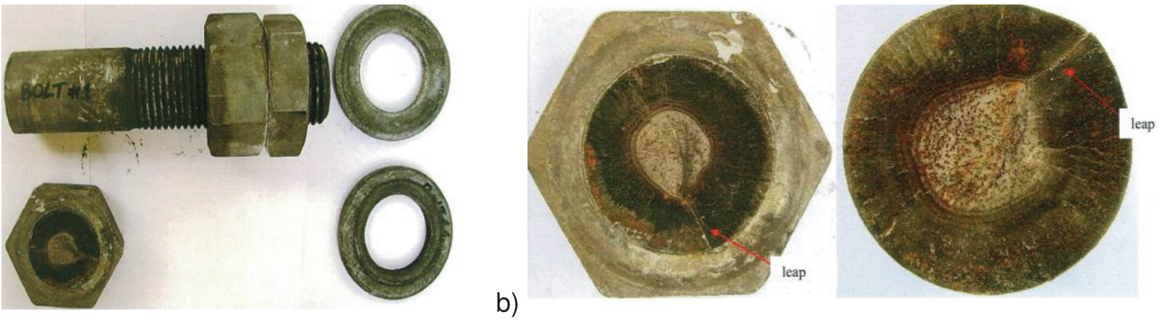


Figure 1 Influence of the corrosion process on the value of permissible stress change of screws M8 x 80, tested inside the salt chamber without zinc coating [own research]

In case of the lack of such a protection the proceeding corrosion processes cause the significant reduction of possibility to carry tensions by construction elements. Corrosion effects are in great measure dependent from the kind of material and from the aggressiveness of the environment. They can cause reduction of the mechanical strength even by the 50%. It is particularly dangerous to fasteners with the higher tensile strength R_m > 1000 MPa [5].

For example in **Figure 1**, the change of the value of the permissible stress value and the pitch diameter of M8x80 screw, tested inside the salt chamber without zinc coating, are presented [own examinations] [6].



a) b)

Figure 2 Appearance of damaged bolts M60 x 260 mounted in a shipyard in South Korea; **a)** whole damaged screws, **b**) head and spinal screws fracture enlargement

Cyclical internal stresses acting on the fastener of steel constructions can contribute to the occurrence of fatigue corrosion. [7]. Both fatigue and hydrogen corrosion are responsible for the sequence of construction disasters. Improper selection of joint elements and its fixing method can much hasten the creation of corrosion centres, and in consequence to cause reduction of the mechanical strength of the entire construction [8, 9, 10, 11]. The simultaneous influence of stresses and the corrosion in screw joint can accelerate the micro-cracks propagation in material. For example, in **Figure 2** a broken bolt M60x260 is presented as a result of such interaction.

To achieve appropriate mechanical properties in corrosion environment for very long operation time the fasteners made of the low-alloyed carbon steel beside galvanizing are subjected to thermochemical and heat treatment. Because fasteners production process consists of a few separate stages, the damage reason determination is not simple. In the course of analysis we should take into account the possibility of defects appearing, including hydriding material, resulting both from the carburizing process, as well as hardening, tempering, picking, phosphating and electrochemical galvanizing [12, 13].

The aim of presented paper was to determine the reasons of cracking of screws M12x130 during operation in real terms despite the positive results of the product quality verification by the Company Laboratory of fasteners supplier.

2. OWN INVESTIGATIONS

2.1. Tested materials

The examinations regarded M12x130 screws made of 42CrMo4 steel containing an additive of Mo that causes a reduction in temper brittleness (0.38-0.45% C, 0.15-0.30 % Si, 0.5-0.90% Mn, max 0.035% P, max 0.035% S, 0.9-1.2% Cr, 0.15-0.30% Mo). The samples after hardening and tempering have been galvanized. In order to reduce hydriding during the screws surface preparation before galvanizing, the standard pickling in 18% HCl was replaced by sharp edge shot peening. Galvanizing was performed according to PN-EN 4042 standard, time in the dehydrogenation process in temperature 200^{0}C, +/- 5^{0}C was 4h [14].

2.2. Investigation method

2.2.1. Hydrogen embrittlement test according to PN-EN ISO 15330 standard

A test of the hydrogen embrittlement conducted according to the standard PN-EN ISO 15330 [15]. Fasteners under the load in the range of yield strength (tightening torque of 225-250 Nm) with the set of sleeves and nut of the same grade regarding mechanical strength as the tested screw. Screws remained in this tightened state for a period of 24 h, and then they were loaded to the initial torque value and were holding in tightened state within the next 24 h. The lack of cracks traces indicated the positive result of the test.

2.2.2. Quantitative analysis of hydrogen content - high temperature extraction method

To determine the steel hydriding level the hydrogen content was measured in chosen cracked samples using high-temperature extraction method - THC600 Leco hydrogen analyser. The determined values were next compared to value measured in the sample not subjected to destructive examinations.

2.2.3. Microscopic investigations

Microscopic examinations were conducted using the electron scanning microscope SEM EVO MA 25 (Zeiss) on a sample that has been taken from a real object after fastener destruction. During the observation character of examined fractures was evaluated. Additionally, to verify the heat treatment effectiveness the Vickers hardness was measured in the sample core (HV30).

2.3. Result analysis

2.3.1. Results of hydrogen embrittlement test

During examinations 15 screws from one lot were subjected to the verification, and none gave the negative result, i.e. after the secondary load adjustment, after 48 h there was no traces of cracking initiation. **Figure 3** presents the screws during the test.

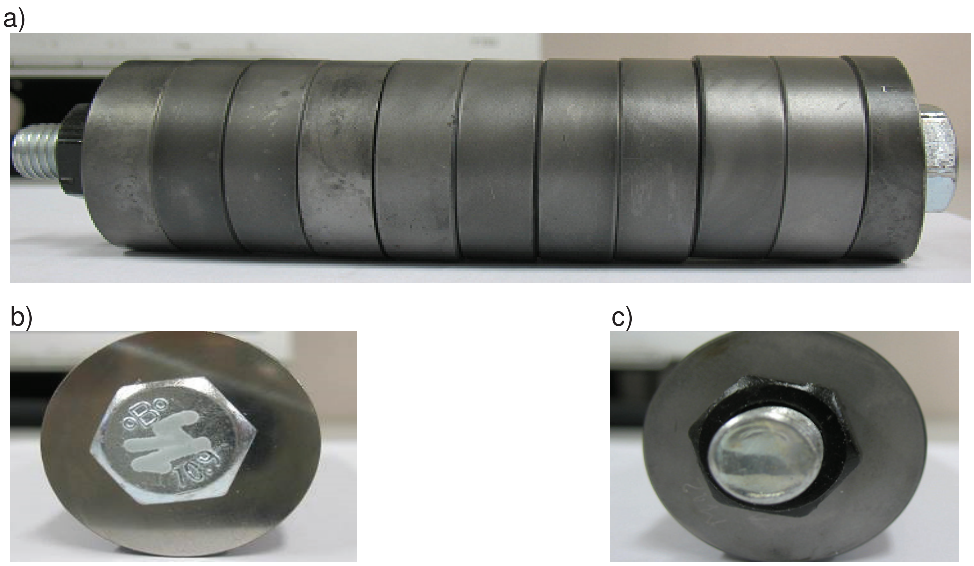


Figure 3 General view of tested screw - a), view of screw assembling from the top and bottom - b), c), acc. to PN-EN ISO 15330 standard [own research]

The performed trial - the hydrogen embrittlement test acc. to PN-EN ISO 15330 standard didn't confirm it occurrence in the examined part of material. However, when mounting the last sleeve with the surface inclination angle of 6 degrees, 5 of the 15 tested screws have been broken near the head within 24 h.

2.3.2. Results of quantitative analysis of hydrogen content

The evaluation of the hydrogen content was performed in the two samples. Sample no. 1 was cut from the head of the screw taken to analysis, which was broken during the first week of exploitation whereas sample no. 2 was taken from the head of brand new specimen from the same production batch. Both samples contained the outer layer coated with zinc plating, the way of test material preparation is shown in **Figure 4**.

Table 1 presents the results of the hydrogen content in the test samples 1 and 2. These values are the arithmetic average of the measurements performed for each sample.

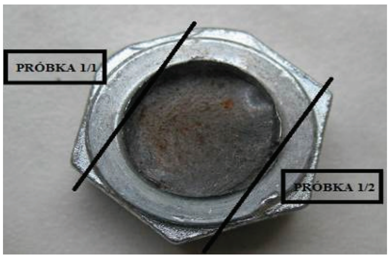


Figure 4 Method of sample preparation to hydrogen content determination, black lines indicate the cutting direction

Table 1 Results of quantitative analysis of hydrogen content in the test samples

Sample No.	kind of sample	H, ppm
1	1 - sample from of the screw head which was broken during operation	18
2	2 - sample from of the screw head without exploitation	20

2.3.3. Microscopic fractures observation

Metallographic examinations concerned the samples which were damaged during exploitation within first operation week.

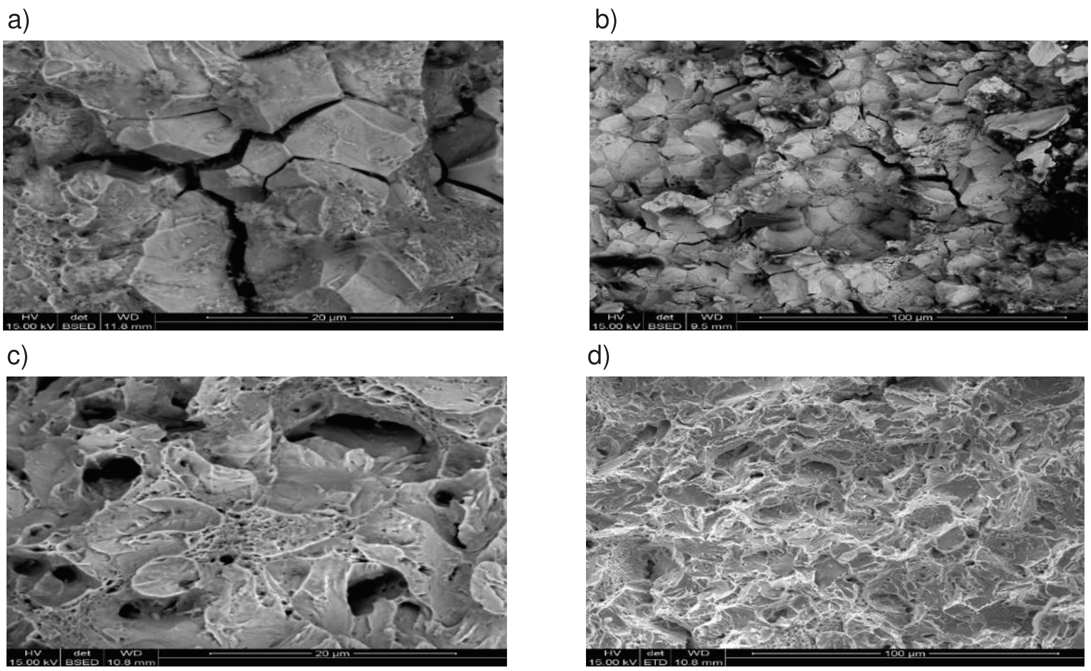


Figure 5 The fracture observed under scanning microscope - sample 1,
a),b) - brittle fracture, c), d) - plastic fracture

Observation was conducted with application of the scanning microscope - on the fractures resulting from spontaneous breakage of samples. Results of observation are presented in **Figure 5**. An appearance of fractures observed under the scanning microscope - **Figure 5 a), b),** explicitly points out to brittle, inter-crystalline cracking which can be caused by the increased hydrogen content. The area where the brittle fracture was observed along the grains boundaries is about 25% of the total surface, the remaining part seen in **Figure 5 c), d)** is a plastic fracture.

Table 2 Hardness values HV30 measured in the investigated samples core

Sample No.	Hardness HV				Average value
1	453.7	453.1	452.6	452.8	453.1
2	453.2	454.6	453.6	452.7	453.5
3	453.9	452.8	452.7	453.1	453.1
4	452.7	451.4	452.9	451.9	452.2
5	453.2	453.5	454.4	454.2	453.8

*standard deviation 1.34

The only doubt about the heat treatment that is possible to express regards the measured hardness values of the core listed in **Table 2**.

The hardness required for the core of screw grade 12.9 should be in the range 385 - 435 HV, whereas in tested samples it's value reached 453 HV [16]. It is clear that in every case it is possible to change the heat treatment process parameters in this way to achieve the hardness lower about 30-40 HV.

Taking into consideration that the scanning microscope observation are explicitly pointing to the possibility of brittle cracking, in the next investigation stage the hydrogen content was measured in broken sample (no. 1) and in the sample not subjected to the hydrogen embrittlement test under load - no.2. Analysis showed that in broken sample the hydrogen content amounted appropriately 18 ppm, whereas the hydrogen content in the not damaged sample was a little bit higher and amounted to 20 ppm.

The reduced hydrogen content in damaged samples can result from breaking the continuity of the zinc-coating which in the reference sample created the natural barrier of hydrogen diffusion. Usually a few ppm (2-4 ppm) level is considered as "harmless" hydrogen content. In similar research regarded screws galvanized on the same production line made of a 23MnB4 steel, the hydrogen content was at a level of 0.5-1 ppm. Considering the mechanism of the hydrogen influence on the reduction of the constructional steel ability to tensions carry (diffusion, trapping, hydrogen interaction with dislocations), and fact that the resistance of steel in this field depends not only from the microstructure, but also from the production technology, the most probable reason of the inspected screws cracking during operation is steel hydriding (during galvanizing) that in the consequence is leading to “hydrogen brittleness”.

3. CONCLUSIONS

The analysis of the results of conducted examinations enabled to express the following conclusions:

- Hydrogen embrittlement tests conducted in this work according to the PN-EN ISO 15330 standard shows that basing on this standard it is not possible to explicitly determine whether a too high hydrogen content was a reason of fasteners damage.
- In order to achieve results corresponding to the actual exposure of tested material to hydrogen embrittlement PN-EN ISO 15330 it is necessary to change the way of loading using the parallel abutment surfaces by changing the angle between the last of the sleeve in contact with a screw head by 6^0 [16]
- Determination of cracks reasons of tested screws requires much more complex examinations - with application of the scanning microscope and the chemical composition analyser, especially hydrogen content is important,

- The initiation and propagation of created cracks could be caused also by too high hardness of inspected screws in the core (453 HV), in comparison to specification requirements that amounts to 385-435 HV for the core,
- Fracture examination with application of scanning microscope confirms existence of the structure characteristic for brittle, inter-crystalline cracking. Additionally, measured hydrogen content values (18-20 ppm) are much higher than typical and can cause the so-called hydrogen brittleness,
- Location of brittle fracture near the outside screws surface may be indicative of the hydrogen transport direction inside the material during the dehydrogenation process. Fracture differentiation indicates that the screws grade 12.9 made of 42CrMo4 zinc electroplated steel require heating dehydrogenation time longer than 4 hours.

REFERENCES

[1] PRACA ZBIORWA. Corrosion Costs and Preventive Strategies in the United State. *Report Federalnej Administracji Autostrad. 2001*

[2] SCHULTZ W.D., THIELE M. Cynkowanie ogniowe jednostkowe. Materiał, Technologia, Powstawanie powłoki, Właściwości, Błędy. *Wyd. Eugen G, Leuze Verlag KG.* 2012

[3] WESOŁOWSKI J. Powłoka cynkowa na stali- powstawanie, budowa i właściwości. *Portal Cynkowniczy*. 2008

[4] KONSTANTINOV V. M., BULOICHYK I. A. 2015. Some aspects of sherardizing implementation during anticorrosion protection of heat treated metal parts. *IOP Conf. Series: Materials Science and Engineering 71*. 2015

[5] JANKA R. M., PIETKUN I., PIETROV L., PIETRZAK R. Wpływ elektrolitycznego wodorowania na korozyjne właściwości stali. *Zeszyty Naukowe Uniwersytetu Opolskiego, Nauki techniczne, Ser. Inżynieria Procesowa w Ochronie Środowiska*. Opole, 2006, 23: 95-101.

[6] SZŁAPA I., JĘDRZEJCZYK D., SKOTNICKI W. The assesment of corrosion impact on mechanical properties change of steel fasteners protected by different zinc coatings - stage 1. *Metal 2015: 24th International Conference on Metallurgy and Materials: proceedings of abstracts.* BRNO : TANGER, 2015 : 1-6

[7] PIETKUN-GREBER I., JANKA R. M. Oddziaływanie wodoru na metale i stopy**.** Effect of hydrogen on metals and alloys. Opole: *Proceedings of ECOpole, 2010 2*: 472-476.

[8] LITWIN M., GÓRECKI M. Błędy wykonawcze podczas realizacji konstrukcji stalowych. *Budownictwo i Architektura*, 2009, 4 : 63-72.

[9] BIEGUS A. Projektowanie konstrukcji stalowych według Euro kodu 3. Część 4 - połączenia śrubowe. Wrocław, 2010 : *Wyd. Politechnika Wrocławska.*

[10] PRACA ZBIOROWA pod redakcją Krystyny Moskwa. Obliczenia dla mechaników*. Kraków, 1997 : Akademia Górniczo - Hutnicza w Krakowie.*

[11] PONIEWAŻ G., KUŹMIERZ L. Podstawy konstrukcji maszyn projektowanie mechanizmów śrubowych oraz przekładni zębatych. *Podręcznik Akademicki. Lublin, 2011 : Politechnika Lubelska, Wydział Mechaniczny.*

[12] SOZAŃSKA M. Niszczenie wodorowe typu „Rybie oczy" wybranych stali dla energetyki. Gliwice, 2006 : *Wyd. Politechnika Śląska Gliwice.*

[13] SZŁAPA I., JEDRZEJCZYK D. Analiza przyczyn uszkodzeń części złącznych cynkowanych galwanicznie. Ochrona przed korozją 10/2016

[14] PN-EN ISO 4042 Części złączne. Powłoki elektrolityczne. 2001

[15] PN- EN ISO 15330 Części złączne. Badanie obciążeniem wstępnym w celu wyznaczenia kruchości wodorowej. Metoda równoległych powierzchni oporowych. 2002

[16] PN - EN ISO 898-1. Mechanical properties of fasteners made of carbon steel and alloy steel - Part 1: Bolts, screws and studs with specified property classes - Coarse thread and fine thread. 2013