THE ASSESMENT OF CORROSION IMPACT ON MECHANICAL PROPERTIES CHANGE OF STEEL FASTENERS PROTECTED BY DIFFERENT ZINC COATINGS - STAGE 1

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Abstract

In the work fasteners - screws M8*80 made of carbon steel 23MnB4 were being examined that are conventionally protected against the corrosion by zinc galvanizing. The research aim was to compare the lifetime/effectiveness of different zinc coatings (galvanic, hot-dip and lamellar), as the anticorrosion protection of steel fasteners. The first research stage consisted in determination a point of reference - kinetic of the screws corrosion process without a protective coating in the climatic chamber, in neutral salt fog according to PN-EN ISO 9227. Both loss of mass and pitch diameter reduction were measured. Next, a change of mechanical properties was determined performing the static tensile test using samples taken after the individual stages of experiment (0 h, 360 h, 624 h, 672 h, 744 h, 888 h, 1000 h). Additionally to enable the more detailed description of the kind and the mechanism of the corrosion from studied fragments of elements the metallographic micro-sections were prepared, on which microstructure and hardness changes were determined. The conducted tests showed that the examined corrosion process apart from essential changes of mass caused also the significant reduction of mechanical properties. In further research the influence of individual types of zinc coating on the kinetics of corrosion process will be presented.

Keywords: Fasteners, zinc coatings, corrosion kinetic

1. INTRODUCTION

Problems concerning durability of materials in natural and artificial environments are extremely important in designing steel structures and metal parts of machines. Corrosion damage is one of the main sources of material loss and a cause of environmental pollution.

As far as the durability of steel constructions is concerned, corrosion has significant importance as it leads to changes in chemical composition of the material that is being affected by the atmosphere. Corrosion makes construction materials oxidation which in turn causes cracks, pits, etc. The combination of tensions with corrosion existed at the same time in fasteners make cracks and pits propagation more quickly. Internal tensions existing in the screw joint lead to fatigue corrosion. This kind of corrosion (trans crystalline process) is difficult to detect which makes impossible to prevent faults caused by such corrosion. Corrosion effects depend on the kind of material and how aggressive the environment is. They can cause lowering of mechanical properties even by 50%. This phenomenon is particularly dangerous for fasteners that have increased mechanical durability R_m > 1000 MPa [1].

Problems with corrosion of steel constructions make multimillion losses every year, in the USA alone such losses cost amount to $276 billion per year, which is 3.1% GDP. Together with prevention cost, the losses are about 7% GDP. For economies like the Polish one, annual financial losses may even reach PLN 100 billion [2].

In developed countries special programs are set up to limit corrosion in certain industry and infrastructure domains. In 2009 World Corrosion Organization (of which The Polish Corrosion Association is a general member) was established, and its aim is to combine effort and achievements in fighting corrosion and spreading knowledge on this subject. That is why proper anticorrosion protection, which prolongs life and reduces the exploitation costs, is becoming a priority for each economy.

There are many protection methods against corrosion, such as structural, material, electrochemical, inhibitor and coating protection. When it comes to protection of steel constructions, coating protection plays a key role. Modern anticorrosion systems must be durable, environment friendly, and economy oriented. Anticorrosion protection of steel constructions consumes huge costs [3].

Both fatigue and hydrogen corrosion is the causes of many building disasters [4]. In the available literature, we encounter studies regarding the influence of construction mistakes made at the stage of building construction designing. Incorrect choice of fasteners and the way of their fixing exerts essential influence on premature corrosion centres creation, and as a result mechanical durability of the whole construction is reduced [5]. Also Królikowska - member of the Polish Corrosion Association points out in her research papers that necessary is to pay attention to the importance of anticorrosion protection in building process. However, in the analysed literature, it is difficult to find detailed information concerning the influence of corrosion on mechanical durability of heat treated screws joints.

There is also limited information available regarding the analysis of proper anti corrosion protection technology, where production parameters would not have a negative effect on the mechanical properties of fasteners. The assessment of the efficiency of anti-corrosion protection of zinc coatings applied with various techniques has been investigated by the authors before [11,12].

2. THE OWN INVESTIGATIONS

2.1. Research facility

The investigation were conducted using as the object the bolts made of steel 23MnB4 (with chemical composition presented in **Table 1**), acc. to standard PN-EN ISO 989-1, with dimensions M8x80, subjected to heat treatment on class 8.8 inside the hardening furnace type of Band-Muffle with protective atmosphere N_2 + 1%/vol C_3H_8. The temperature of heat treatment was 900 °C, the time treatment - 40 min., oil cooling rate 80 °C/s, tempering temperature - 480 °C, the holding time 55 min.

The results of bolts corrosion tests without anticorrosion zinc coating (galvanic, hot-dip, lamellar and thermo-diffusion) are a point of reference for the assessment of protective zinc coatings effectiveness and will be the supplement to the database of the knowledge regarding the proper selection of galvanizing technology to the specific application.

a) b) c)

Fig. 1 The screws M8x80 appearance: a) - before corrosion test, b) - after corrosion test, c)- after cleaning the surface - removal of corrosion products

Table 1 Chemical composition of 23MnB4 steel

Source of results	Chemical composition of 23MnB4 steel [%]									
	C	P	S	Mn	Al	Si	Cu	Cr	Ni	Fe
acc. PN-EN ISO 898-1	0.15-0,4	0.025	0.025	ng*	ng*	ng*	ng*	ng*	ng*	98
acc. spectrometer	0.201	0.0096	0.0071	1.01	0.018	0.084	0.181	0.281	0.067	98

ng* - not given

2.2. Preparation of test samples

For research test 18 pcs. of bolts from one production batch were taken. Bolts were divided into 6 groups of 3 pcs each and placed into a salt spray chamber (type ASCOT capacity 1000 l, the company laboratory of F.Ś. BISPOL S.A.). The corrosion test were performed acc. PN-EN 9227:2012 standard [7]. The tests parameters were as follows: test solution - NaCl 50 +/- 5g/dm^3, solution density: 1.035 g/cm^3, condensate density: 1.033 g/cm^3, solution pH: 6.7, air pressure: 1 bar, temp. inside chamber: 35 °C. After taking out from the chamber bolts were cleaned (12 % HCl with 0.1 % corrosion inhibitor) and directed for the next investigations.

3. METHODOLOGY AND THE RESEARCH RESULTS

3.1. Samples physical parameters and mechanical properties

The measurements were performed at the laboratory of F.S. BISPOL SA company, using tensile testing machine ZD-40 made by WMW. The bolts were tested in sets 3 pcs after the corrosion time: 360, 624, 672, 744, 888 and 1000 h and the results were averaged [8]. Beside R_m, $Rp_{0.2}$ also Rockwell hardness was measured. The corresponding results are presented in **Table 2** and **Fig. 2**.

Table 2 Mechanical properties of investigated screws

BOLT - grade 8.8 M 8X80, MATERIAL - 23MnB4									
Test/tolerance value	Measure unit	Before test	Time of corrosion process						
			360 h	624 h	672 h	744 h	888 h	1000 h
Rm [800-1000]	MPa	929	909	878	871	855	854	830
$Rp_{0,2}$ [min 640]	MPa	776	825	811	805	741	792	761
Rockwell hardness [22-32]	HRC	29	28	28	29	27	27	27

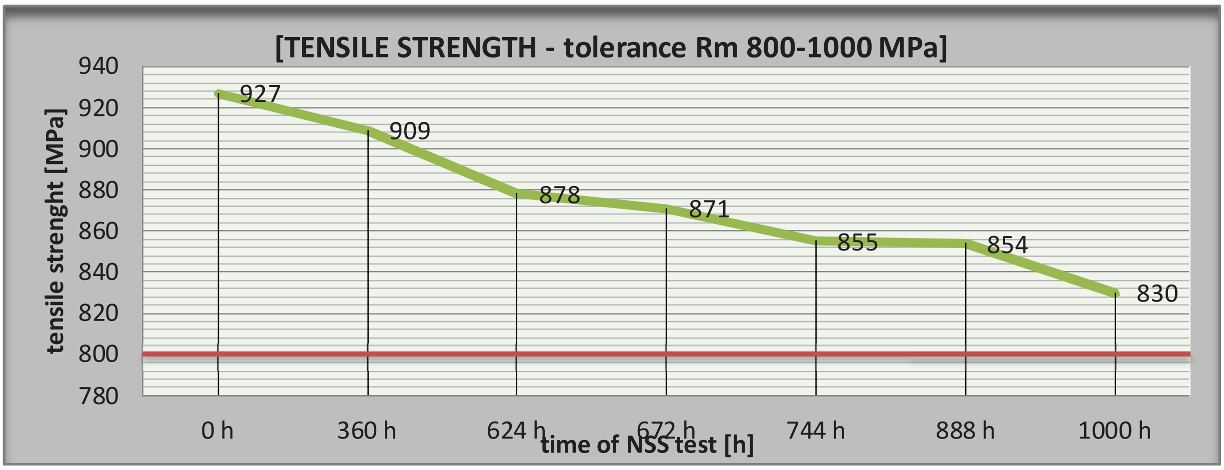


Fig. 2 Influence of corrosion on the tensile strength change

Additionally during the experiment the physical parameters describing the corrosion kinetic were measured: the weight of samples before and during the NSS test, pitch diameter measurement. Achieved results are presented in **Figs. 3, 4**.

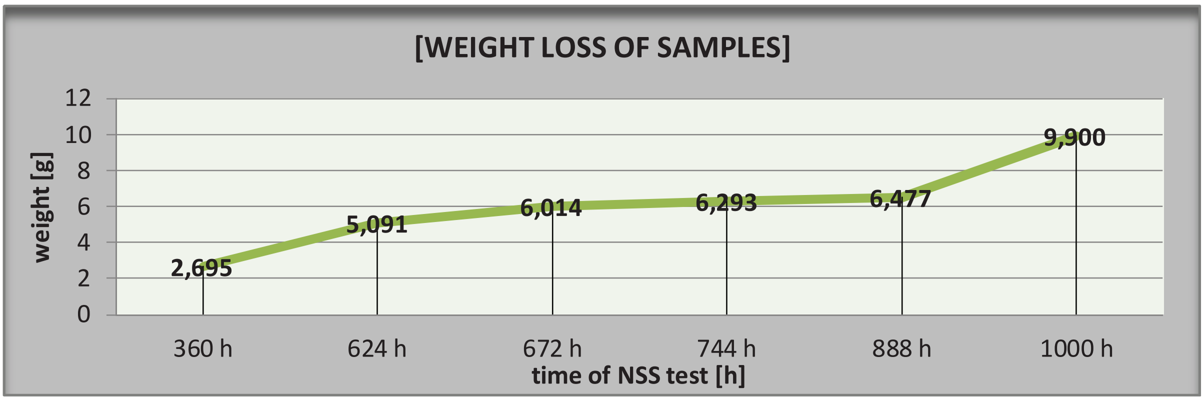


Fig. 3 Weight change during the corrosion process

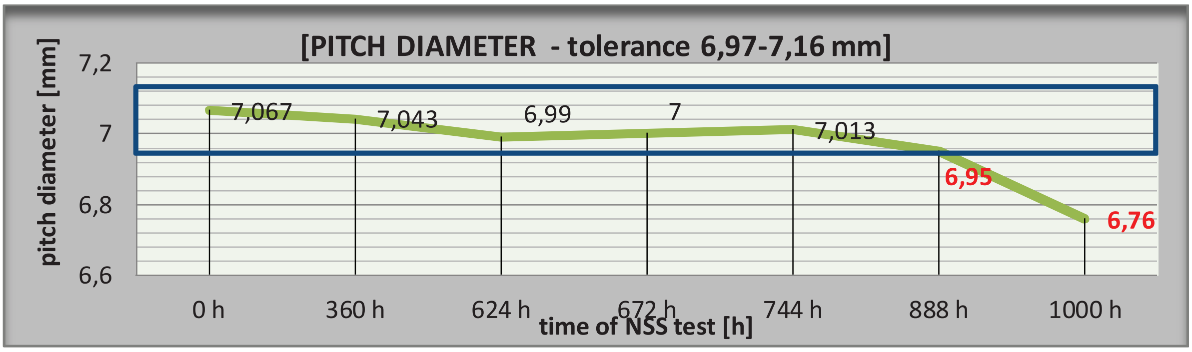


Fig. 4 Pitch diameter change during the corrosion process

$V_c = \Delta m/S = 1049.9523\ g/m^2$ [9]

Vc - unit of weight loss - weight loss expressed per 1 m^2 of the test [g/m^2]

Δm - the difference in weight of the sample before and after the test corrosion [g]

S -area of the samples [m^2]

3.2. Metallographic investigations

Metallographic investigation was conducted for all samples. Metallographic specimens were prepared in classic way. The observation was realized using optical - LM microscope. Results are presented in **Fig. 5**.

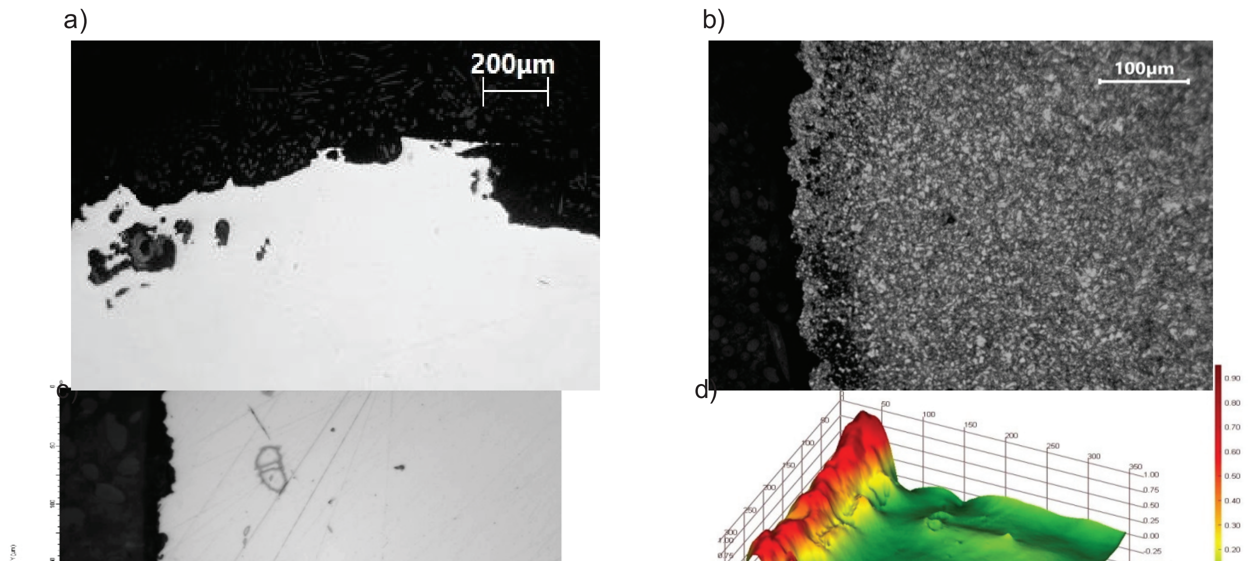
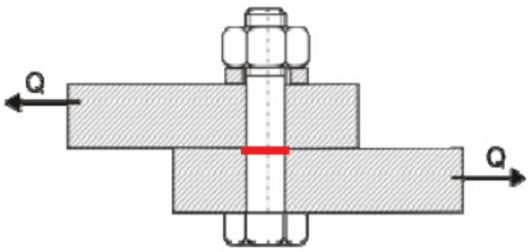


Fig. 5 The cross section of corroded samples: a, b - after 1000 h, c, d - after 672 h



τ_t - shear stress

Q - the force acting on the screw

S - the active screw area

$$\tau_t = Q/S = 4Q/\pi d^2 n \le k_t$$

Fig. 6 The equation to screw joint shear strength calculation [6,8]

4. RESULTS DISCUSSION

The starting point to own investigation results analysis is screw joint presented in **Fig. 6** which shows shear forces acting on a fastener where the minimum Q force causes rupture. Q force for the class 8.8 fastener is equal to 29 200 N [8].

Considering the graph of the relationship of the pitch diameter change in time, it has been observed that after 1000 h the sample pitch diameter decreased by 5% in relation to the sample diameter before the test, and after 1000 h the pitch diameter value is out of the acceptable tolerance for the construction of the fastener assessed in the NSS test [8]. Generally, basing upon the achieved corrosion kinetics (**Figs. 2 - 4**) two different stages of corrosion processes can be clearly distinguished. Up to 888 h the corrosion process runs uniformly, and after 888 h the rate of corrosion process increases drastically. This has also been confirmed by the results of measurement of screw weight loss, where the graph of the relationship of weight loss to the time of the test in the range from 0 to 88 h (R^2 = 0.9225) satisfy a logarithmic dependence, whereas in the range from 888 to 1000 h the relationship satisfy a linear dependence. This phenomenon is explained by the microscopic investigation of the cross-section **Fig. 5a, b**, where numerous pitting corrosion points have been observed in the range from 888-1000 h. Minimum tensile strength value - Rm measured in the sample before the test was 927 MPa, and after 1000 h Rm decreased by 97 MPa, which is equal to 11% of the starting value, and means that the Rm value for the fastener is in the lower range of acceptance according to the constructors' recommendations [8]. The decrease in Rm value satisfies a linear trend in entire experiment time range (R^2 = 0.9548), that is why we can assume, that further influence of the corrosion environment will decrease the Rm value below 800 MPa after 1300 h. Analysing the equation in **Fig. 6** and taking into consideration the Rm and d - pitch diameter values measured during the test, it can be stated that there is a linear relationship between the pitch diameter and the shear stress value. The decrease in pitch diameter causes an increase in shear force leading to faster rupture.

5. CONCLUSIONS

On the basis of conducted preliminary examinations it is possible to express the following conclusions:

- For bolts made of low carbon alloyed steel and subjected to heat treatment, the corrosion environment has a significant influence on the strength of calculated joint
- As a result of corrosion tests in salt chamber after 888 h, the pitch diameter of the analyzed bolts decreased below the lower tolerance limit, also tensile strength value Rm decreased essentially, which makes the shear forces more dangerous to the projected screw joint
- Considering different zinc coating (galvanizing, hot-dip, lamellar, thermos-diffusion) as the anti-corrosion protective layers of screws joints only with reference to hot-dip zinc coating the special requirements can be formulated
- Using the hot-dip zinc galvanizing it is necessary to remember about change the thread division tolerance because the thickness of hot-dip zinc coating is higher than 60 µm and in the case of normal tolerances will result in lack of assembly possibility
- Hot-dip zinc galvanizing process should be conducted in max. 480 °C, because this parameter can't be higher than screws tempering temperature

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