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FORECASTING THE CHANGE OF YIELD STRESS POINT ON STEEL WITH CORROSION ACCORDING TO CORROSION INFLUENCE FOR MILITARY SHELTERS

ANTONIO SHOPOV
VSU"Luben Karavelov", Sofia, shopoff@mail.bg

SVETLOZAR GANEV
University of Chemical Technology and Metallurgy, Sofia, sv_ganev@abv.bg

Abstract: *There are numerous kinds of shelters for military or civilian use, which due to weather conditions or other factors have begun to corrode. The negative impact of corrosion on steel shelters is well known. This usually results in reduction of geometric characteristics, structural changes, surface defects, a change in elastic modulus, ductility and most importantly the conversion of steel as a ductile material into a brittle material. Numerous studies have been carried out on this topic, but there is still no universal formula with which to determine approximately how the yield stress point of the steel would change due to the corrosive effects over the years. We have collected experimental data from tests of corroded steel samples and by applying the mathematical model - polyponal approximation have established empirical dependencies, which can serve to pre-determine the expected yield stress point of corroded steel. The empirical data processing, using the stochastic and the average methods, has been used. From the applied diagram it is established that the dependence of the change on yield stress point in months has the same function, but stretched over time. The derived dependencies can be accepted with sufficient accuracy in practice and can serve in a preliminary analysis of the reliability of the different military shelters.*

Keywords: *corrosion, influence, shelters, forecasting.*

1. INTRODUCTION

The military shelters are divided into three main types - underground, above-ground and semi-excavated [1]. The period from 1947 to 1991 is known as the Cold War [2-4]. During this period, military shelters or firing positions were built in abbundance in order to provide protection from possible attacks [2-4]. According to the military principles, there are three basic types - air-raid shelters, fallout shelters and bunkers [1]. The air-raid shelter is structure built to protect against bomber planes dropping bombs over a large areas [2]. The fallout shelter is a shelter designed specifically for a nuclear war, with thick walls made from materials intended to block the radiation from fallout resulting from a nuclear explosion [2]. The bomb shelters are equally amenable to civilians and military use, while a bunker is more commonly associated with military use [2]. The bunkers may be hastily assembled as a part of an ongoing military advance, or to hold a line [2]. In their essence, they represent a type of their construction, which is calculated and dimensioned according to the normative requirements in force at the time of its construction [2]. Due to the non-maintenance of these military facilities, corrosion is present on them. Corrosion occurs on steel elements due to various factors. On figure 1 is shown a military shelter, of a bunker type with corrosion. It is known that corrosion has negative impacts on steel such as: loss of geometric characteristics, structural changes, loss of mechanical properties and others [5-9]. We should look for ways to predict the corrosive impact. Some authors offer a variety of dependencies to determine the influence of corrosion on mechanical properties [5-13], but there are no equations that summarize the experimental results and might be easily used by military and civil engineers in practice. Experimental data for the study of corroded elements is available [5-11]. After treatment describing with a polynomial function should be correlated with the effect of corrosion on values on yield stress point.

Figure 1. Military shelter of a bunker type in Albania with corrosion of steel elements

2. ALGORITHM AND METHOD

Numerical mathematical methods are widely used in research. Two methods are applied in engineering and scientific practice [14]. The first is called deterministic model and this is a system in which no element of chance is involved in the development of future system states [14]. The second model is called Stochastic and it derives from the theory of probabilities. The stochastic process (random process) is the opposite of the deterministic process [14-15]. In this method, the associated stochastic (random) areas are in the process as mathematical objects, and are usually defined as a set of random variables [15].

Research in the field of stress-strain diagram has existed for more than 200 years. Until 15 years ago, the results were always presented in graphical form, as a stress-strain diagram that meant that the stress was on the y-axis and the strain was on the x-axis. In order to use these graphical data, an algorithm should be applied to extract the corresponding values from the graphical diagram [18-22] and to process them by using numerical mathematical methods.

The stress-strain diagrams obtained after the test are only available as digital images according to the requirements of the test methodology. Software is available for extracting graph data from raster images (e.g. scanned images), including open source software (an example of this is [23]). Methods for performing such extraction are described in literature and algorithms and program codes are proposed [18-24]. Most methods require the operator to determine the coordinates of the abscissa and ordinate axis. Some methods use manual graph tracking [18-21], which is not applicable when processing a large number of graphs. Using the methods described in literature, an algorithm, optimized for the specific case, is implemented.

Matlab environment was used for the implementation of the algorithm [18-19].

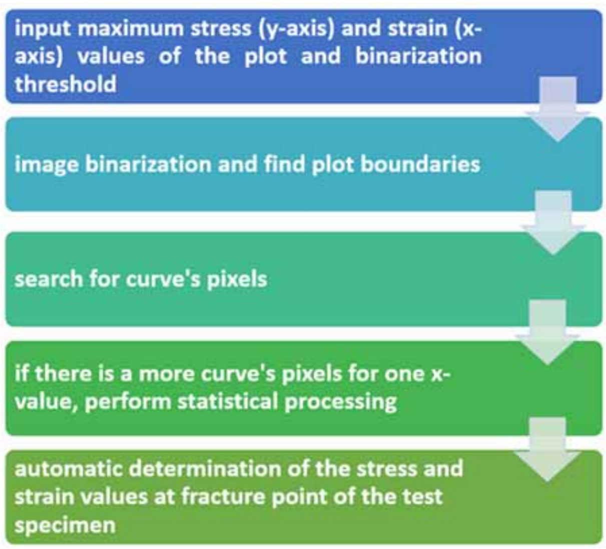

Figure 2. A block diagram of the algorithm implemented

The following possibilities are realized in the algorithm:

– automatic detection of chart boundaries;

– additional statistical processing in case of the presence of more curve's pixels for one x-value;

– automatic determination of the stress and strain values at fracture point of the test specimen.

The block diagram of the algorithm is shown in fig. 2. The only data to be entered are maximum stress (y-axis) and strain (x-axis) values of the plot and binarization threshold [21-23]. The result is the x and y values of the stress-strain diagram. Due to the representation of the curve as pixels in raster images, several y-values are often obtained for a given x-value, whereby additional statistical processing is performed to determine the specific y-value.

3. ESTABLISHING OF EQUATIONS

Experimental data has been presented and is available in some papers as well as certain indicators from mechanical properties due to the corrosive impact [5-11]. We use the data and apply stochastic and average methods in order to establish a basic value of yield stress point changes depending on corrosion influence. After that we have processed experimental data using a polynomial approximation and we have found a different equation for all the cases. According to the standard ISO 12944 there are six corrosion categories from C1 to CX, but in standard ISO 9223 the corrosion categories are five from C1 to C5. The type of the corrosion category is irrelevant in the process of evaluation, so we use ISO 12944. The difference is that CX category is applicable for extreme corrosion stress.

3.1. Corrosion category C1

After the processing by the stochastic method and the average method these results are shown on table 1. The dependence between the change of the yield stress point and the time of the influence of the corrosion for this category, using the results indicated in Table 1, is shown on fig.3.

Table 1. Results after the processing for C1

time, [months]	Yield stress point, [MPa]	
	stochastic method	average method
0	420.67	396.54
9138	357.92	338.72
14769	358.92	342.55
24923	355.61	326.96
34892	355.00	308.16
46154	332.60	313.44
54000	376.92	340.29
64615	317.85	291.21
73108	292.92	259.10
77262	303.91	297.96

Using the polynomial approximation [10-13] from fig.3, functional dependence for the yield stress point and the time of the influence of the corrosion (in months) is established in equations (eq. 1 and eq. 2).

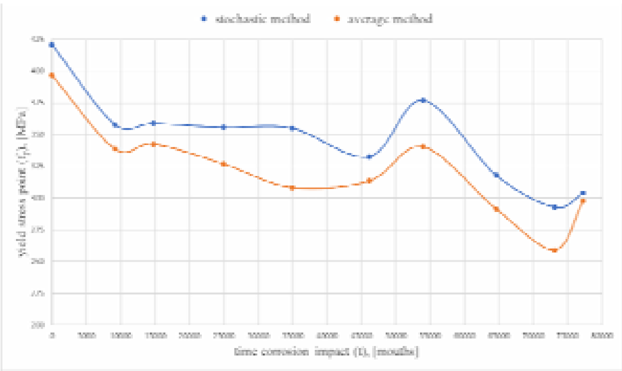

Figure 3. Graphics on dependence on yield stress point during the time of the influence of the corrosion – C1

Stochastic method

$$f_y(t) = 3.0059.10^{-38}.t^9 + 1.0528.10^{-32}.t^8 - 1.5404.10^{-27}.t^7 + 1.2219.10^{-22}.t^6 - 5.7094.10^{-18}.t^5 + 1.5980.10^{-13}.t^4 - 2.60381.10^{-9}.t^3 + 2.2680.10^{-5}.t^2 - 8.5762.10^{-1}.t + 420.67 \quad (1)$$

Average method

$$f_y(t) = -1.0446.10^{-38}.t^9 + 3.6436.10^{-33}.t^8 - 5.3093.10^{-28}.t^7 + 4.2096.10^{-23}.t^6 - 1.9847.10^{-18}.t^5 + 5.7118.10^{-14}.t^4 - 9.8616.10^{-10}.t^3 + 9.4808.10^{-6}.t^2 - 4.2757.10^{-2}.t + 396.54 \quad (2)$$

3.2. Corrosion category C2

After the processing by the stochastic method and the average method these results are shown on table 1. The dependence between the change of the yield stress point and the time of the influence of the corrosion for this category, using the results indicated in Table 2, is shown on fig.4.

Table 2. Results after the processing for C2

time, [months]	Yield stress point, [MPa]	
	stochastic method	average method
0	420.67	396.54
475	357.92	338.72
768	358.92	342.55
1296	355.61	326.96
1814	355.00	308.16
2400	332.60	313.44
2808	376.92	340.29
3360	317.85	291.21
3802	292.92	259.10
4018	303.91	297.96

Using the polynomial approximation [10-13] from fig.4, functional dependence for the yield stress point and the time of the influence of the corrosion (in months) is established in equations (eq. 3 and eq. 4).

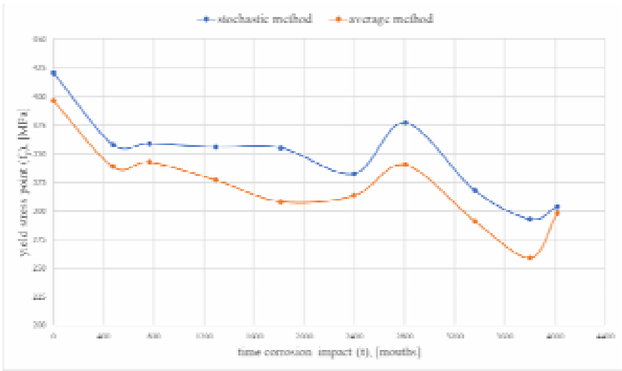

Figure 4. Graphics on dependence on yield stress point during the time of the influence of the corrosion – C2

Stochastic method

$$f_y(t) = -1.0821.10^{-26}.t^9 + 1.9708.10^{-22}.t^8 - 1.4995.10^{-18}.t^7 + 6.1855.10^{-15}.t^6 - 1.5029.10^{-11}.t^5 + 2.1874.10^{-11}.t^4 - 1.8535.10^{-5}.t^3 + 8.3951.10^{-3}.t^2 - 1.6506.t + 420.67 \quad (3)$$

Average method

$$f_y(t) = -3.7613.10^{-27}.t^9 + 6.8221.10^{-23}.t^8 - 5.1694.10^{-19}.t^7 + 2.1314.10^{-15}.t^6 - 5.2257.10^{-12}.t^5 + 7.8203.10^{-9}.t^4 - 7.0208.10^{-6}.t^3 + 3.5095.10^{-3}.t^2 - 8.2265.10^{-1}.t + 396.54 \quad (4)$$

3.3. Corrosion category C3

After the processing by the stochastic method and the average method these results are shown on table 1. The dependence between the change of the yield stress point and the time of the influence of the corrosion for this category, using the results indicated in Table 3, is shown on fig.5.

Table 3. Results after the processing for C3

time, [months]	Yield stress point, [MPa]	
	stochastic method	average method
0	420.67	396.54
238	357.92	338.72
384	358.92	342.55
648	355.61	326.96
907	355.00	308.16
1200	332.60	313.44
1404	376.92	340.29
1680	317.85	291.21
1901	292.92	259.10
2009	303.91	297.96

Using the polynomial approximation [10-13] from fig.5, functional dependence for the yield stress point and the time of the influence of the corrosion (in months) is established in equations (eq. 5 and eq. 6).

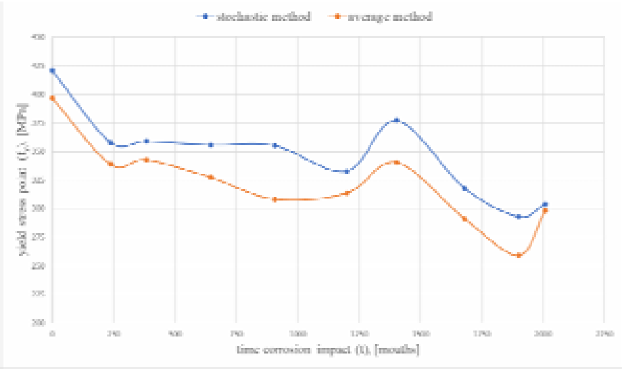

Figure 5. Graphics on dependence on yield stress point during the time of the influence of the corrosion – C3

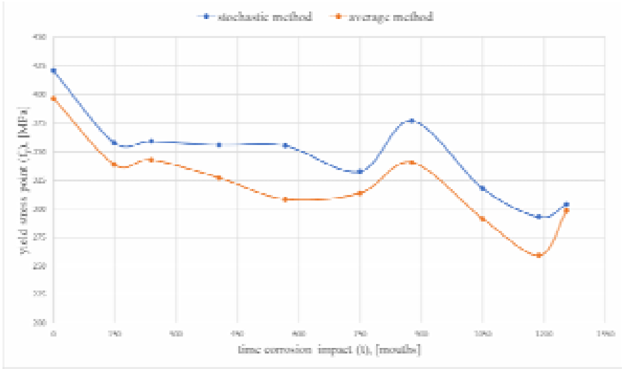

Figure 6. Graphics on dependence on yield stress point during the time of the influence of the corrosion – C4

Stochastic method

$$f_y(t) = -5.54028.10^{-24}.t^9 + 5.0453.10^{-20}.t^8 - 1.9193.10^{-16}.t^7 + 3.95873.10^{-13}.t^6 - 4.8092.10^{-10}.t^5 + 3.4999.10^{-7}.t^4 - 1.4828.10^{-4}.t^3 + 3.3580.10^{-2}.t^2 - 3.3013.t + 420.67 \quad (5)$$

Average method

$$f_y(t) = -1.9240.10^{-24}.t^9 + 1.7448.10^{-20}.t^8 - 6.6104.10^{-17}.t^7 + 1.3627.10^{-13}.t^6 - 1.6705.10^{-10}.t^5 + 1.2499.10^{-7}.t^4 - 5.6110.10^{-5}.t^3 + 1.4026.10^{-2}.t^2 - 1.6444.t + 396.54 \quad (6)$$

3.4. Corrosion category C4

After the processing by the stochastic method and the average method these results are shown on table 1. The dependence between the change of the yield stress point and the time of the influence of the corrosion for this category, using the results indicated in Table 4, is shown on fig.6.

Table 4. Results after the processing for C4

time, [months]	Yield stress point, [MPa]	
	stochastic method	average method
0	420.67	396.54
149	357.92	338.72
240	358.92	342.55
405	355.61	326.96
567	355.00	308.16
750	332.60	313.44
878	376.92	340.29
1050	317.85	291.21
1188	292.92	259.10
1256	303.91	297.96

Using the polynomial approximation [10-13] from fig.6, functional dependence for the yield stress point and the time of the influence of the corrosion (in months) is established in equations (eq. 7 and eq. 8).

Stochastic method

$$f_y(t) = -3.8087.10^{-22}.t^9 + 2.1678.10^{-18}.t^8 - 5.1542.10^{-15}.t^7 + 6.6445.10^{-12}.t^6 - 5.0451.10^{-9}.t^5 + 2.2948.10^{-6}.t^4 - 6.0764.10^{-4}.t^3 + 8.6008.10^{-2}.t^2 - 5.2838.t + 420.67 \quad (7)$$

Average method

$$f_y(t) = -1.3236.10^{-22}.t^9 + 7.5024.10^{-19}.t^8 - 1.7766.10^{-15}.t^7 + 2.2890.10^{-12}.t^6 - 1.7538.10^{-9}.t^5 + 8.2019.10^{-7}.t^4 - 2.3011.10^{-4}.t^3 + 3.5945.10^{-2}.t^2 - 2.6330..t + 396.54 \quad (8)$$

3.5. Corrosion category C5

After the processing by the stochastic method and the average method these results are shown on table 1. The dependence between the change of the yield stress point and the time of the influence of the corrosion for this category, using the results indicated in Table 5, is shown on fig.7.

Table 5. Results after the processing for C5

time, [months]	Yield stress point, [MPa]	
	stochastic method	average method
0	420.67	396.54
59	357.92	338.72
96	358.92	342.55
162	355.61	326.96
227	355.00	308.16
300	332.60	313.44
351	376.92	340.29
420	317.85	291.21
475	292.92	259.10
502	303.91	297.96

Using the polynomial approximation [10-13] from fig.7, functional dependence for the yield stress point and the time of the influence of the corrosion (in months) is established in equations (eq. 9 and eq. 10).

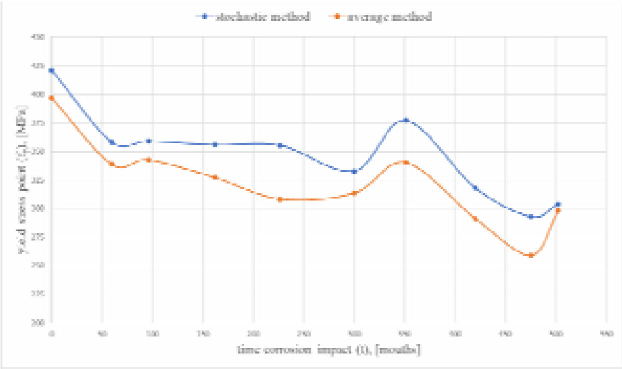

Figure 7. Graphics on dependence on yield stress point during the time of the influence of the corrosion – C5

Stochastic method

$$f_y(t) = -1.4524.10^{-18}.t^9 + 3.3065.10^{-15}.t^8 - 3.1446.10^{-12}.t^7 + 1.6215.10^{-9}.t^6 - 4.9247.10^{-7}.t^5 + 8.9597.10^{-5}.t^4 - 9.4898.10^{-3}.t^3 + 5.3729.10^{-1}.t^2 - 13.2050.t + 420.67 \quad (9)$$

Average method

$$f_y(t) = -5.0473.10^{-19}.t^9 + 1.443.10^{-15}.t^8 - 1.0839.10^{-12}.t^7 + 5.586.10^{-10}.t^6 - 1.712.10^{-7}.t^5 + 3.2024.10^{-5}.t^4 - 3.5938.10^{-3}.t^3 + 2.2457.10^{-1}.t^2 - 6.5819.t + 396.54 \quad (10)$$

3.6. Corrosion category CX

After the processing by the stochastic method and the average method these results are shown on table 1. The dependence between the change of the yield stress point and the time of the influence of the corrosion for this category, using the results indicated in Table 6, is shown on fig.8.

Table 6. Results after the processing for CX

time, [months]	Yield stress point, [MPa]	
	stochastic method	average method
0	420.67	396.54
17	357.92	338.72
27	358.92	342.55
46	355.61	326.96
65	355.00	308.16
86	332.60	313.44
100	376.92	340.29
120	317.85	291.21
136	292.92	259.10
143	303.91	297.96

Using the polynomial approximation [10-13] from fig.8, functional dependence for the yield stress point and the time of the influence of the corrosion (in months) is established in equations (eq. 11 and eq. 12).

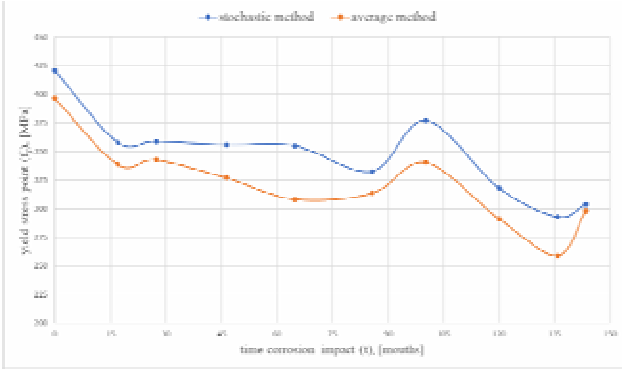

Figure 8. Graphics on dependence on yield stress point during the time of the influence of the corrosion – CX

Stochastic method

$$f_y(t) = -1.1439.10^{-13}.t^9 + 7.4408.10^{-11}.t^8 - 2.0218.10^{-8}.t^7 + 2.9786.10^{-6}.t^6 - 2.5846.10^{-4}.t^5 + 1.3435.10^{-2}.t^4 - 0.40655.t^3 + 6.5764.t^2 - 46.1795.t + 420.67 \quad (11)$$

Average method

$$f_y(t) = -3.9715.10^{-14}.t^9 + 2.5725.10^{-11}.t^8 - 6.9613.10^{-9}.t^7 + 1.025.10^{-6}.t^6 - 8.9747.10^{-5}.t^5 + 4.7966.10^{-3}.t^4 - 0.1538.t^3 + 2.7463.t^2 - 23.0025.t + 396.54 \quad (12)$$

The probability of results – for stochastic results is 83.21% and for average results is 78.55%.

If we remove values from the formulas, as another researcher has done [10-11], we establish with sufficient practical accuracy, a basic non-liner equation (eq. 13) [10-11].

$$f_y(t) = A_9.t^9 + A_8.t^8 + A_7.t^7 + A_6.t^6 + A_5.t^5 + A_4.t^4 + A_3.t^3 + A_2.t^2 + A_1.t + f_y \quad (13)$$

Where: A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8 and A_9 are constant values and need to be determined experimentally in every case [12-13].

4. CONCLUSION

From the graphically presented results in the present study, it has been established that there is a relationship between the corrosion category and the change in yield stress point due to corrosion. The function obtained is the same in the different types. The only thing that differs is the speed with which the change in value will take place. For now, we can confirm a function of 9th degree, on which function the constant numbers are variable and depend on various factors. The established equations can be used in practice to determine the value of the yield stress point in advance and wound be useful in performing the necessary calculations to determine the residual suitability of the military shelters.

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