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Behaviour Analysis of Corroded Wires Based on Statistical Models

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ABSTRACT: Steel wires are the primary components of a lifting wire rope. The behaviour of a wire governs the behaviour of the whole of the cable. The physico-chemical processes like rates of degradation due to the environment (corrosion, etc.) are different for each layer, external layers being more exposed.
The analysis of steel wires behaviour is traditionally based on statistical models describing the variability of its properties. For this purpose a statistical study was carried out on two populations of healthy and corroded wires by applying the Student distribution to select the most reliable results and the Weibull distribution to define the survival probability and the failure probability.
Keywords:- Steel wires; wire rope; corrosion; statistical study.

I. INTRODUCTION

The wire ropes are widely used in harbours, on ships and in many industrial fields. The safety of a wire rope is closely related to the life safety and equipment safety [1]. The quality and wearing degree of ropes significantly influences safety and reliability of mining hoists, cranes, elevators and air transportation. Wire rope consists of three parts: wires, strands, and core. In the manufacture of rope, a predetermined number of wires are laid together to form a strand. Then a specific number of strands are laid together around a core to form the wire rope (Figure1).

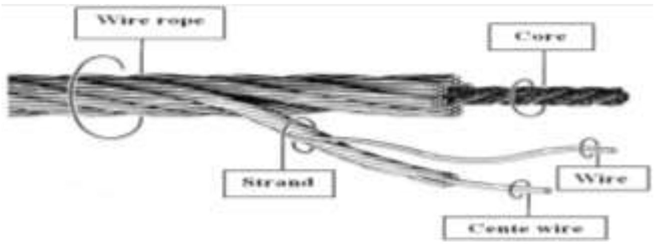


Fig.1: Basic components of a typical wire rope

The wire ropes after the entry into service are subjected to the action of time and consequently to the ageing which is one of the main causes of reduction their reliability [2]. The aim of our work is to analyse the wire's maximum stress based on statistical studies. The wires are extracted of a wire rope and immerged in 30% of H_2SO_4.

II. MATERIALS & METHODS

A. Materials

The tested wires (Figure 2) are extracted from wire rope of type 19x7 and antigyratory structure (1x7 + 6x7 + 12x7) 8 mm in diameter, composed of steel light greased, metal core, right cross, preformed, used especially in tower cranes and suspension bridges.

Fig. 2: Tested wire

The chemical composition of the steel wires is given in Tables 1.

Table 1: The Chemical composition of the material

Composition	C	Si	Mn	S	P
Percentage	1,478	2,04	3	0,144	0,091

The minimum length of the specimens is equal to the length of the test 200 mm plus the necessary for the mooring. Therefore, a length of 300 mm is anticipated as the length of the test for the wires. The measurements tolerance in the length is ± a millimeter for all samples [3]. Dimensions of the wire are shown in figure 3.

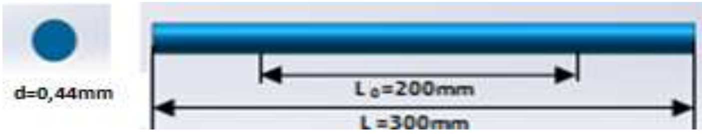


Fig. 3: Dimensions of the studied wire

The apparatus used for mechanical characterization tests is a traction machine "Zwick Roell" of a 2.5 kN load cell (Figure 4).

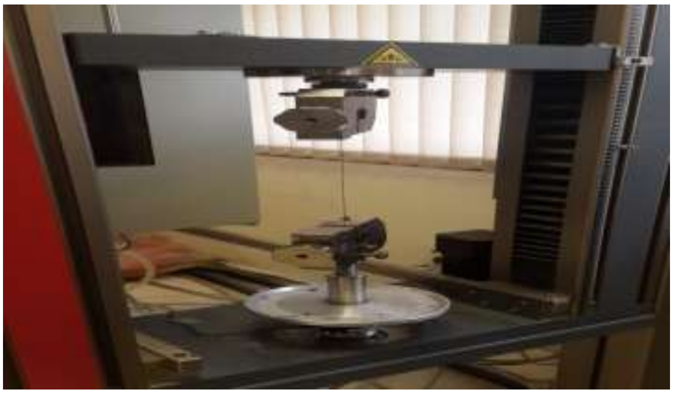


Fig. 4: Zwick Roell testing machine (2.5 KN)

B. Corrosion methods

The wires were cut at a length of 300 mm. The areas of 100 mm length were defined in the middle of the specimen (Figure 5), and then they were immersed in 30% H2SO4 solution at room temperature (Figure 6) [4].

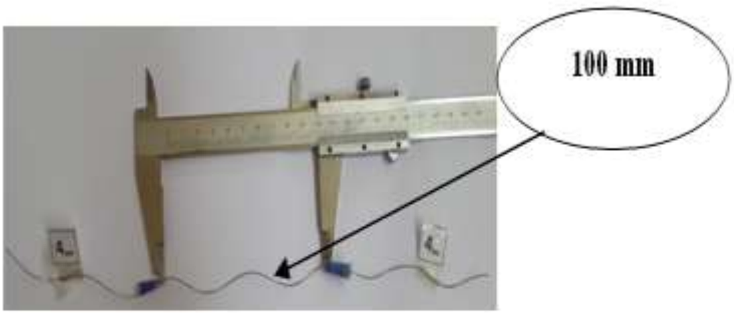


Fig. 5: Dimensions of the areas defined in the middle of the wire

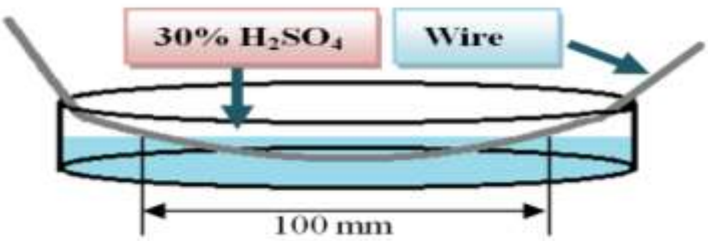


Fig. 6: Schema of accelerated corrosion testing

C. Statistical distributions

- **Student distribution**

Student distribution is used for finding confidence intervals for the population mean when the sample size is small and the population standard deviation is unknown, in our case it is used to regulate the average distribution of the tensile tests[5].

$$P\left[-t(\alpha,\mu);\alpha \leq \frac{X-\mu}{s/\sqrt{n}} \langle +t(\alpha,\mu);\alpha\right]=1-\alpha \qquad (1)$$

$$P\left[X-t(\alpha,\mu);\alpha.\frac{s}{\sqrt{n}}\langle\mu\langle X+t(\alpha,\mu);\alpha.\frac{s}{\sqrt{n}}\right]=1-\alpha \qquad (2)$$

Where:

X: The sample mean;

n: sample size;

: n-1;

s: Standard deviation;

: Risk threshold.

III. RESULTS AND DISCUSSION

A. Tensile strength

The direct traction tests were carried out on two batches of 17 wires (virgin, corroded). Table 2 shows the maximum stress values obtained for virgin wires and corroded wires.

Table 2: maximum stress values obtained for virgin wires and corroded wires

N° Test	Virgin wires	Corroded wires
1	1970	1368
2	1980	1375
3	1990	1384
4	2036	1406
5	2084	1431
6	2135	1443
7	2173	1468
8	2216	1493
9	2256	1506
10	2288	1512
11	2326	1525
12	2358	1562
13	2397	1566
14	2432	1575
15	2478	1581
16	2522	1586
17	2595	1593

Average	2249,17	1492,58
Standard deviation	198,61	79,34

B. Applicability of student distribution for steel wires

The average and standard deviation estimated of maximum stress that corresponds at 17 specimens subjected to static tests are:

- **Virgin wires**

We have

X= 2249,17 ; s= 198,61 ; n=17 ; α= 0,01 ; t (α/2; 16)= 2,921

Resulting:

$$\mu = 2249.17 \pm 2.921\sqrt{\frac{39445.9}{17}} = [2108.46\,;2389.87]$$

- **Corroded wires**

We have

X= 1492,58 ; s= 79,34; n=17 ; α= 0,01 ; t (α/2; 16)= 2,921

Resulting:

$$\mu = 1492.58 \pm 2.921\sqrt{\frac{79.34}{17}} = [1436.37\,;1548.78]$$

The specimens belonging to the confidence intervals determined for the two cases are grouped in Table 3:

Table 3: Font Sizes for Papers

Virgin wires		Corroded wires	
N° Test	**Maximum stress**	**N° Test**	**Maximum stress**
6	2135	6	1443
7	2173	7	1468
8	2216	8	1493
9	2256	9	1506
10	2288	10	1512
11	2326	11	1525
12	2358		

C. Weibull distribution application

The aim of this statistical study is to provide a statistical processing to derive the maximum stress that can be applied on the material so that the failure probability (damage) is less than 1% ,and then estimate the survival probability (reliability) and the probability of failure[6].

The probability of survival of the test specimens subjected to mechanical stresses could be modeled using the following Weibull distribution:

$$Ps = e^{-\left(\frac{\sigma}{\sigma_0}\right)^m} \qquad (3)$$

Where

Ps: Probability of survival;

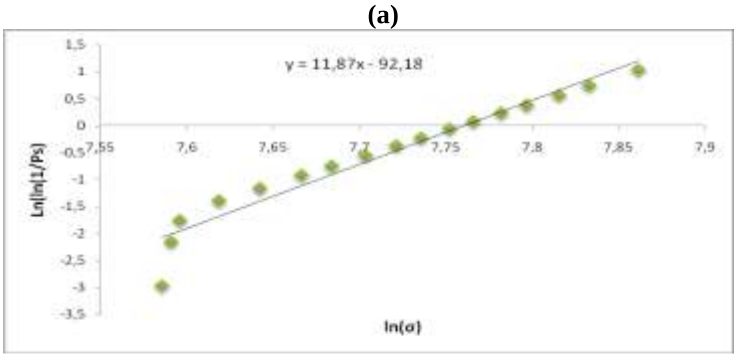
σ : Applied stress;

σ_0 : Constant scale parameter with the same dimensions as used for the stress;;

m : dimensionless and called the weibull modulus.

This line yields estimates for the both parameters of the Weibull distribution. Specifically, the parameter m is the slope of the fitted line and the parameter is the exponent of the intercept of the fitted line.

(a)



(b)

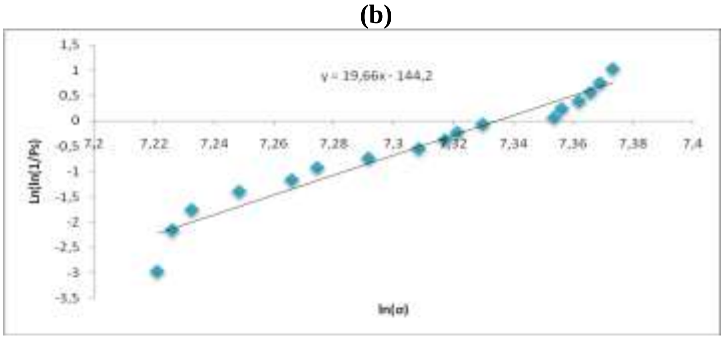


Fig. 6: ln σ en fonction de Ln (ln (1/Ps) with (a) Virgin wires and (b) Corroded wires

Table 4 shows the values of the Weibull parameters determined for virgin wires and corroded wires.

Table4: Weibull parameters

Weibull parameters	Virgin wires	Corroded wires
m	11.87	19.66
σ_0	2358.53	1532.55

D. Survival probability determination

We used the equation (4) to calculate the defiance probability:

$$Ps + Pf = 1 \qquad (4)$$

Where
Ps: Survival probability;
Pf: defiance probability.

- **Virgin wires**

The probability of survival and the probability of failure curve in function of maximum stress are presented in figure 7.

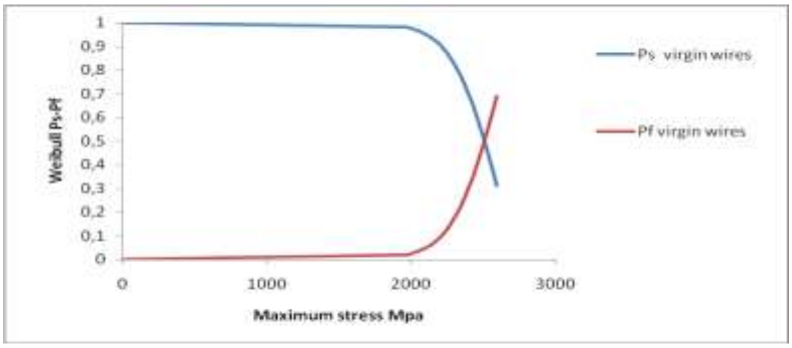


Fig. 7: Survival probability and failure probability curves in function of maximum stress for virgin wires

The value of maximum stress obtained that could be applied on the material so that the failure probability is less than 1% is:

$$\sigma = 160078 \text{ MPa}$$

- **Corroded wires**

The probability of survival and the probability of failure curve in function of maximum stress are presented in figure 8.

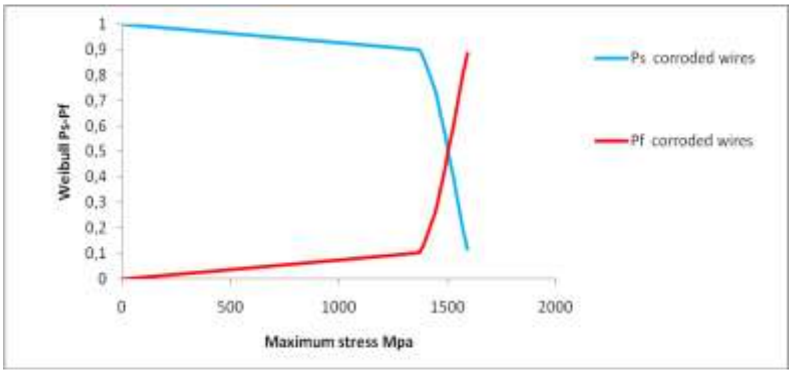


Fig. 8: Survival probability and failure probability curves in function of maximum stress for corroded wires

The value of maximum stress obtained that could be applied on the material so that the failure probability is less than 1% is:

$$\sigma = 121281 \text{ MPa}$$

E. Superposition maximum stress curves for virgin and corroded wires

The probability of survival and the probability of failure curves in function of maximum stress for virgin and corroded wires are presented in figure 8.

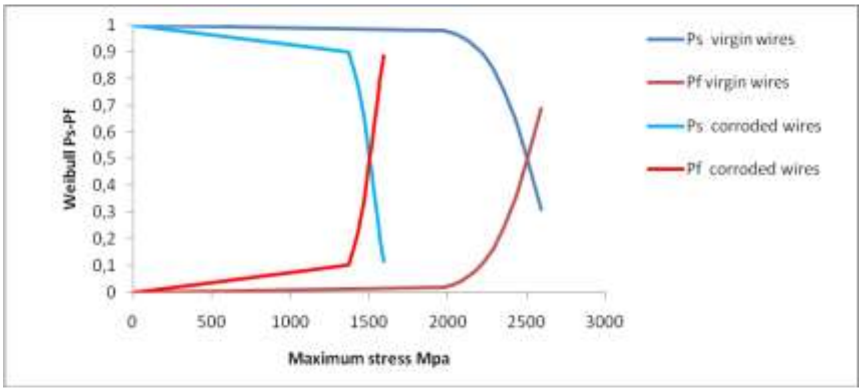


Fig. 8: Superposition maximum stress curves for virgin and corroded wires

According to the curve in figure 8, we see a reduction in reliability of corroded wires that approaching to 40%. This allowed us to observe the corrosion effect on the mechanical behavior of the wires.

IV. CONCLUSIONS

The behavior analysis of corrosion-resistant steel wires by applying the student distribution allowed us to determine the confidence intervals for virgin wires and corroded wires.

On the other hand, the Weibull distillation allowed us to plot the probability of survival curves and probability of failure for virgin and corroded wires and consequently to understand the corrosion effects on the lifetime of the wires because a great reduction of Reliability has been noticed.

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