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 (Figure 1).

![Fig.1: Basic components of a typical wire rope](image)

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 H2SO4.

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](image)
The chemical composition of the steel wires is given in Tables 1.

<table>
<thead>
<tr>
<th>Composition</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>1.478</td>
<td>2.04</td>
<td>3</td>
<td>0.144</td>
<td>0.091</td>
</tr>
</tbody>
</table>

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](image)

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)](image)

**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](image)

![Fig. 6: Schema of accelerated corrosion testing](image)
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].

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

  Where:
  \(X\): The sample mean;
  \(n\): sample size;
  \(\alpha\): n-1;
  \(s\): Standard deviation;
  \(\mu\): 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>
<thead>
<tr>
<th>N° Test</th>
<th>Virgin wires</th>
<th>Corroded wires</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1970</td>
<td>1368</td>
</tr>
<tr>
<td>2</td>
<td>1980</td>
<td>1375</td>
</tr>
<tr>
<td>3</td>
<td>1990</td>
<td>1384</td>
</tr>
<tr>
<td>4</td>
<td>2036</td>
<td>1406</td>
</tr>
<tr>
<td>5</td>
<td>2084</td>
<td>1431</td>
</tr>
<tr>
<td>6</td>
<td>2135</td>
<td>1443</td>
</tr>
<tr>
<td>7</td>
<td>2173</td>
<td>1468</td>
</tr>
<tr>
<td>8</td>
<td>2216</td>
<td>1493</td>
</tr>
<tr>
<td>9</td>
<td>2256</td>
<td>1506</td>
</tr>
<tr>
<td>10</td>
<td>2288</td>
<td>1512</td>
</tr>
<tr>
<td>11</td>
<td>2326</td>
<td>1525</td>
</tr>
<tr>
<td>12</td>
<td>2358</td>
<td>1562</td>
</tr>
<tr>
<td>13</td>
<td>2397</td>
<td>1566</td>
</tr>
<tr>
<td>14</td>
<td>2432</td>
<td>1575</td>
</tr>
<tr>
<td>15</td>
<td>2478</td>
<td>1581</td>
</tr>
<tr>
<td>16</td>
<td>2522</td>
<td>1586</td>
</tr>
<tr>
<td>17</td>
<td>2595</td>
<td>1593</td>
</tr>
</tbody>
</table>

| 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
    \[
    X= 2249.17 ; s= 198.61 ; n=17 ; \alpha= 0.01 ; t (\alpha/2; 16)= 2.921
    \]
    Resulting:
    \[
    \mu = 2249.17 \pm 2.921 \sqrt{\frac{30445.9}{17}} = [2108.46 ; 2389.87]
    \]

  - **Corroded wires**
    We have
    \[
    X= 1492.58 ; s= 79.34 ; n=17 ; \alpha= 0.01 ; t (\alpha/2; 16)= 2.921
    \]
    Resulting:
\[ \mu = 1492.58 \pm 2.921 \sqrt{\frac{79.54}{17}} = \left[ 1436.37; 1548.78 \right] \]

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

<table>
<thead>
<tr>
<th>Virgin wires</th>
<th>Corroded wires</th>
</tr>
</thead>
<tbody>
<tr>
<td>N° Test</td>
<td>Maximum stress</td>
</tr>
<tr>
<td>6</td>
<td>2135</td>
</tr>
<tr>
<td>7</td>
<td>2173</td>
</tr>
<tr>
<td>8</td>
<td>2216</td>
</tr>
<tr>
<td>9</td>
<td>2256</td>
</tr>
<tr>
<td>10</td>
<td>2288</td>
</tr>
<tr>
<td>11</td>
<td>2326</td>
</tr>
<tr>
<td>12</td>
<td>2358</td>
</tr>
</tbody>
</table>

### Table 3: Font Sizes for Papers

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:

\[ Ps = e^{-\left(\frac{\sigma}{\sigma_0}\right)^m} \]  \hspace{1cm} (3)

Where

- \( Ps \): Probability of survival;
- \( \sigma \): Applied stress;
- \( \sigma_0 \): 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 \( \mu \) is the exponent of the intercept of the fitted line.

\[ \text{Fig. 6: } \ln \sigma \text{ en fonction de } \ln(1/Ps) \text{ with (a) Virgin wires and (b) Corroded wires} \]

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

<table>
<thead>
<tr>
<th>Weibull parameters</th>
<th>Virgin wires</th>
<th>Corroded wires</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$</td>
<td>11.87</td>
<td>19.66</td>
</tr>
<tr>
<td>$\sigma_0$</td>
<td>2358.53</td>
<td>1532.55</td>
</tr>
</tbody>
</table>

D. Survival probability determination

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

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

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](image)

  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](image)

  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.
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.

**REFERENCES**


