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# Tensile test of a strand with 2 broken wires artificially damaged and life prediction

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**ABSTRACT**

*Steel wire ropes are elements of an essential structure which are subjected in their utilization at variety of mechanical stresses. They necessitate regular, periodic and delicate monitoring and maintenance. Indeed, a slightest failures result in substantial discomfort economically and socially. Thus, the necessity to ensure and guarantee the reliability of a complex structure such as cables; is an issue which is extremely important.*
*Failures of steel wire ropes are associated with various degradations that particularly affect the wires and the strands, resulting in a significant reduction in cables resistance over time, which leading to a brutal break.*
*The aim of this study is to predict the damage of a strand constituting a steel wire rope, based upon an experimental tensile test of a strand artificially damaged. Thereafter and with the establishment of the relation Damage-Reliability, the critical life fraction βc is determined that predicts the moment of critical damage and thus to intervene in time for a predictive maintenance of the system.*

***Keywords*** - *Damage, Predictive maintenance, Reliability, Steel wire rope, strand, Tensile test.*

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## I. INTRODUCTION

Wire ropes have many applications: lifting loads, stowage floating structures, bracing bridges, prestressing of concrete structures...

They are characterized by a very complex architecture (Fig.1). The base components of the steel wire rope is the drawn wire [1]. The wires are then twisted to form a strand; the wire rope is finally made with the strands, which describe helices around the core during the cabling operation [2]. This special structure permits the wire ropes to resume loads despite the break of one or more wires [3]. Furthermore, their bending flexibility allows their easy winding before or during utilization.

However, this specific conception of wire ropes which has many advantages has also some disadvantages, since the passage rate through the winding appliances as well the numerous successive accelerations and decelerations could cause deformation or local damage.

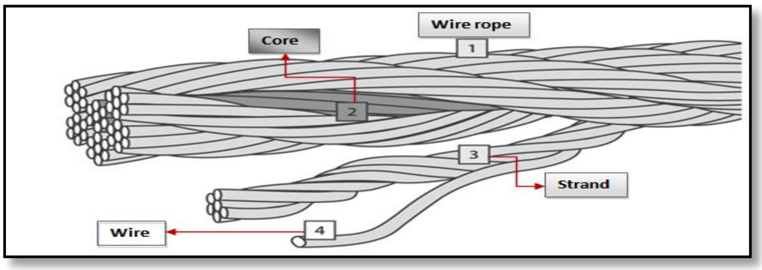


Fig.1. Components of a steel wire rope

During the tensile test of a strand with 2 wires artificially ruptured, it’s observed that the resistance drops at the rupture of each wire, where does the interest of our study which is predict the damage of a ruptured strand, based upon an experimental tensile test and subsequently determine the critical fraction of life βc. Such a study could be beneficial for manufacturers due to its low cost and rapidity.

## I. MATERIAL

Our approach is to study the behavior of a strand belonging to a hoist wire rope of type 19x7 and antigyratory structure (1x7 + 6x7 + 12x7) (Fig.2). The cable is composed of two layers of strands wired in opposite directions; this construction is generally utilized to support a large axial load with comparatively small flexure or tensional stiffness [4].

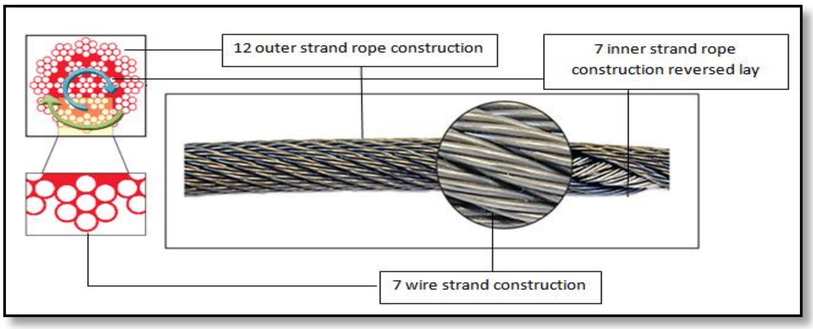


Fig.2. Hoist Wire Rope of type 19x7 and ant gyratory construction (1x7 + 6x7 + 12x7)

The studied strands are composed of 7 individual wires; a core wire and six peripheral wires disposed helically around the core wire (Fig.3). To obtain specimens of the strand, a suitable length of the cable was cut and strands were de-wiring (wiring off). The minimum length of the samples strand is equal to the length of the test plus the necessary for the mooring. Therefore, a length of 300 mm is anticipated as the length of the test for the strands. The measurements tolerance in the length is ± a millimeter for all samples [3]. Dimensions of the strand are shown in Fig.3:

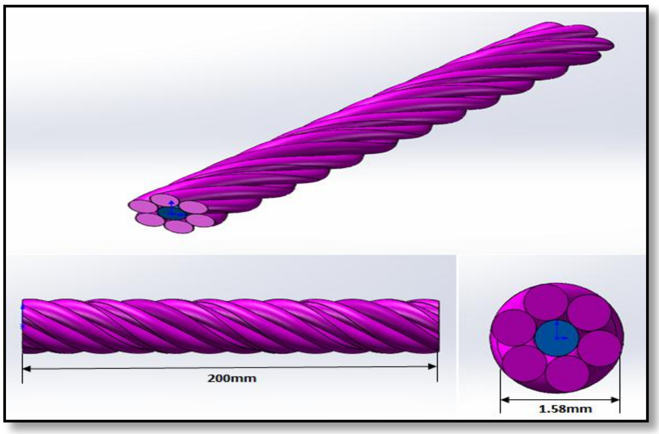


Fig 3. Dimensions of the studied strand

## II. EXPERIMENTATION

To understand a material behavior, it is essential to identify it, namely to analyze the chemical and mechanical characteristics.

A. **Chemical Composition :** The chemical composition is obtained by spectrometric analysis using a spectrometer peak spark. The result is summarized in Table 1:

Table1. Chemical composition of the material

| **Elements** | **C** | **Si** | **Mn** | **P** | **S** | **Cr** | **Mo** | **Ni** |
|---|---|---|---|---|---|---|---|---|
| **%** | 1,478 | 2,04 | 3 | 0,091 | 0,144 | 0,182 | 0,208 | 0,120 |

It is noticed that the wire rope is made of a low alloy steel with high percentage of carbon (about 1,478%); They are obtained by the cold wire-drawing process, which consists of passing the wire through a conical die until the desired diameter. Indeed, this reduction of diameter causes a hardening of the metal and then provides a high tensile strength.

**B. Mechanical properties:** To extract the mechanical properties of the material, tensile tests were performed in the Public Testing Laboratory and Studies, on virgin strands specimens.
The fixation of the samples is performed by means screwed wedges on both ends of the strand in order to prevent sliding of the samples during the tests.

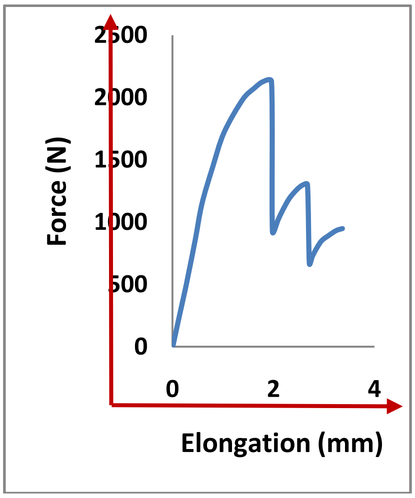


Fig 4. Test Curve of the applied force in function of the elongation for the virgin strand

The mechanical properties of the virgin strands are reported in the table.2:

Table 2. Mechanical properties of the material

| Young's modulus | Poisson's ratio | elastic limit | Breaking stress |
|---|---|---|---|
| E=189 GPa | ν=0,3 | σe=1035 MPa | $\sigma_r$=1992 MPa |

## III. RESULTS AND DISCUSSION

### IV.1 Static tensile test on strands with 2 wires artificially broken

The test curve of the applied force in function of the elongation for the strand with 2 broken wires artificially damaged is given by the (Fig.5).

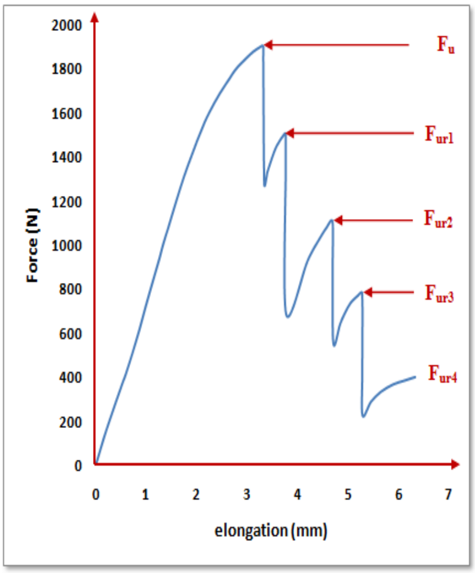


Fig 5. Test Curve of the applied force in function of the elongation for the strand with 2 wires artificially broken

According to this diagram, we observed that the strand has an ultimate residual force of 1890 N that drops on each rupture of a constituent wire then resumes its stiffness until reaching the corresponding final rupture value over the last strand 402 N. This can be translated by a loss of resistance of strand according to the number of broken wires. The values of residual ultimate strength are reported in Table 3.

Table 3. Values of residual ultimate strength

| **Fu (N)** | **Fur1 (N)** | **Fur2 (N)** | **Fur3 (N)** | **Fur4 (N)** |
|---|---|---|---|---|
| 1890 | 1502 | 1106 | 782 | 402 |

### IV.2 Calculation of static damage

The model of static damage (Ds) is to determine the evolutions of the force whose variations are mainly due to damage. Then we quantify the damage by the variable Ds expressed as:

$$Ds = \frac{1-\frac{Fur}{Fu}}{1-\frac{Fa}{Fu}} \qquad (1)$$

Where :
**Fu:** the value of the maximum ultimate strength
**Fur:** the value of the ultimate strength
**Fa:** the force just before the break

Throughout the test, we are following the phenomenon of damage from the initial state with 2 wires artificially damaged to the complete rupture of the specimen by measuring the ultimate residual force in function of the life fraction β that corresponds to ratio of the number of broken wires on the total number of wires, this phenomenon is described by the damage parameter $D_S$ Eq (1) .

We have:

- In the initial state with 3 broken wires: β = 3/7 → Fu = Fur → D = 0

-In the final state: β = 1 → F = Fur → D = 1

The variation of the static damage according to the life fraction is illustrated by the curve:

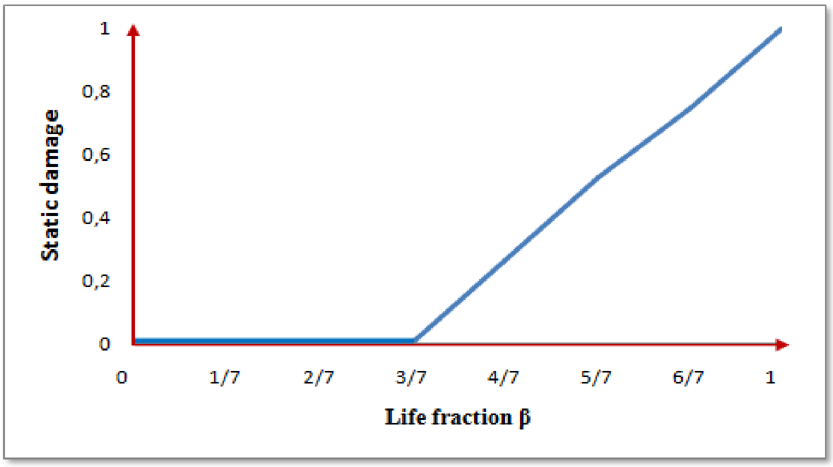


Fig 6. Evolution of the static damage depending on the life fraction

The increase of the damage means the loss in resistance of static tensile strength, this loss evolves when the number of broken wires becomes more important. It is a fragile damage with irreversible deformation that reduces the ultimate strength of the material.

### IV.3 Relationship Damage –Reliability

When a system is in operation under static solicitations, its physical properties undergo a progressive degradation, so we often need to reduce the probability of sudden failure.
The reliability theory permits to evaluate the probability of failure and considers the uncertainties associated with different variables.

Reliability varies inversely to the damage [5]. Intuitively; there must be a relationship between these two parameters. This allows us to write:

$$R_s(\beta) + D_S(\beta) = 1 \qquad (2)$$

The resulting equation allows us to plot the variation in the reliability superposed on the damage:

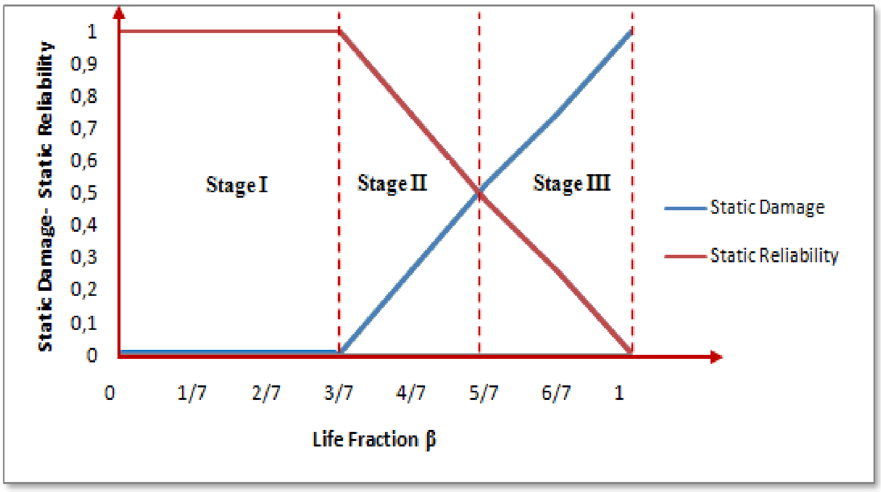


Fig7. Superposition of static curves Damage - Reliability depending on the life fraction

The superposition of the curves Rs and Ds indicates a critical intersection point (Fig 7) which coincides with an inversion of position.

In fact, the reliability was initially greater than the damage and becomes weaker beyond this point, which corresponds to the acceleration of damage. From Fig 7, we can distinguish three stages:

- Stage I that corresponds to the initiation of an elastic damage;
- Stage II that corresponds to progressive damage;
- Stage III that corresponds to the brutal damage;

The coordinates of the critical point are: βc (0.5, 5/7) which indicate that starting from 5/7 (71% of broken wires), the damage of strand that belongs to stage III becomes unstable. Thus, when these non-dimensional ratios are reached, a predictive maintenance intervention is necessary.

## IV. CONCLUSION

A study of damage and reliability study was conducted based on a static tensile test, which permits to estimate the life time of a strand extract from a hoist wire rope of type 19x7 and antigyratory structure and with 2 wires artificially broken.

Thereafter, with the establishment of the relationship Damage-Reliability, we could determine the critical life fraction, which permits to predict the instant of critical damage and thus to intervene at the appropriate moment.

On an industrial scale, these kind of studies have an interest in any company that uses regularly or occasionally lifting devices and have as objective to prevent accidents related to the use of cables with a low cost based solely on a tensile test.

Furthermore, it is also planned to study the behaviors of an entire wire rope with the only data cable geometry and the damage of the strand.

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