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Characterization of residual energy loss and Damage Prediction of 7-wire strand extracted from a steel wire rope and subjected to a static test

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Abstract

The nature of a wire rope is such that there is an energy stored when it is in service. This introduces a potential safety issues due to an unexpected release of this energy. Therefore, regular, periodic and delicate monitoring and maintenance is necessary for personnel safety. Throughout the life of a wire rope, the wires and strands that make up this cable are subjected to several degradations indicating a loss of the original energy, which leads to very rapid deterioration leading to sudden and violent rupture.

Being able to predict the reliability and the damage of a strand (7 wires) constituting a wire rope (19x7) is the main purpose of this work. Based on an experimental tensile test , three stages of damage were distinguished which allowed us to determine the critical life fractionβ_c and thus to intervene in time for predictive maintenance..

Key Words:

Reliability; damage; Strand; Energy; Tensile test; predictive maintenance

I. Introduction:

Wire ropes are very important tensile structural memberswidely used in the field of mine hoist system, crane, transport machinery, due to its various advantages of excellent flexibility and high axial strength.

Wire ropes are constructed of a complex assembly of steel wiresthat vary according to specific applications.They made up of the basic components illustrated in figure 1; each individual cold-drawn wire [1] is helically arranged around a central wire to form strands. These strands are formed around a central core to make a wire rope?

The size and number of wires in each strand, as well as the size and number of strands in the rope greatly affect the mechanical properties. In general, a large number of small size wires and strands produce a flexible rope with good resistance to bending fatigue. This geometry is also important and fabulous benefit namely the ability to resume loads despite the break of one or more wires [2].

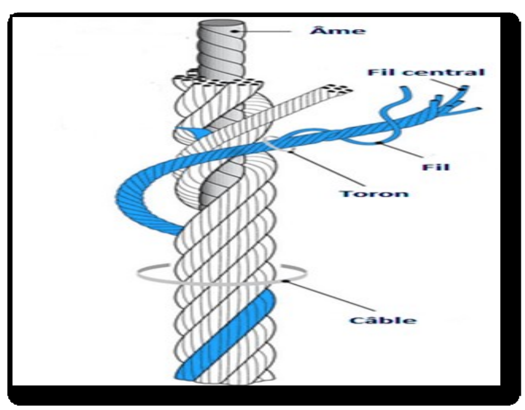

Figure 1. Steel wire rope construction

During the tensile test of a strand, it's observed that the resistance drops at the rupture of a wire or more and resume its stiffness and therefore the decrease of the stored energy, where does the interest of our study which is predict the damage of 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.

II. Material

This study focuses on the behavior of a strand extracted from a steel wire rope of type 19x7 (The first refers to the number of strands in the rope and the second to the number of wires per strand) and antigyratory construction (1x7 + 6x7 + 12x7) (Figure 2); such a structure is composed of a number of strands that are laid up in opposite directions to produce a non-rotating effect [3].The physical model and force conditions of this type of wire rope were studied in literature [4][5][6].

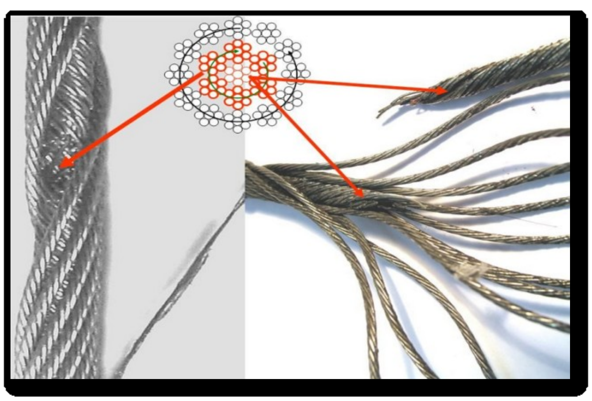

Figure 2. Steel Wire Rope of type 19x7 and antigyratory construction (1x7 + 6x7 + 12x7)

The studied strands include a straight central wire, called central around which are spun six wires in one layerto form a 7-wire strand.Single strand under axial tensile load were treated by some researchers for example [7][8].

II.1. 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
%	1,478	2,04	2	0,091	0,0144	0,182	0,208

Wire rope is made of a plain carbon steel with high carbon content (about 1,478%) and a very fine grain structure achieved through isothermal transformation (patenting), and work hardening by successive drawing, the metal and then provides a high tensile strength.

II.2. Mechanical properties:

The mechanical properties extracted from strength-elongation diagram of the strands specimensare reported in the table.2:

Young's modulus	Poisson's ratio	elastic limit (MPa)	Breaking stress (MPa)
E=189 GPa	ν=0,3	σe=1035	σr=1992

Table 2. Mechanical properties of the material

III. Experimentation

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 [9]. Dimensions of the strand are shown in Figure 3:

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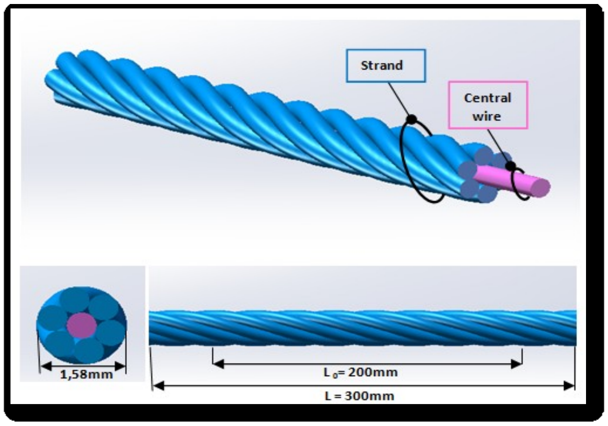

Figure 3. Dimensions of the studied strand

Tensile test of strand wire ropes of diameter 1,85 mm was realized at 5 virgin specimensin the Public Testing Laboratory and Studies (LPEE) by means of zwick roell testing machine (10 KN) (Figure 4).

The fixation of the samples is performed by means screwed wedges on both ends of the strandin order to prevent sliding of the samples during the tests.

Figure 4.Zwick Roell testing machine (10 KN)

IV. Results

IV.1. Strength-elongation diagram

In the tensile tests carried out on the extracted strands, we found that resistance drop in each failure of a number of constituent wire followed by a resumption of stiffness until reaching the final rupture of the strand .This can be translated as loss of strength as a function of the number of broken wires accompanied a loss of energy. Figure 5 shows the test curve of the applied force versus theelongation.

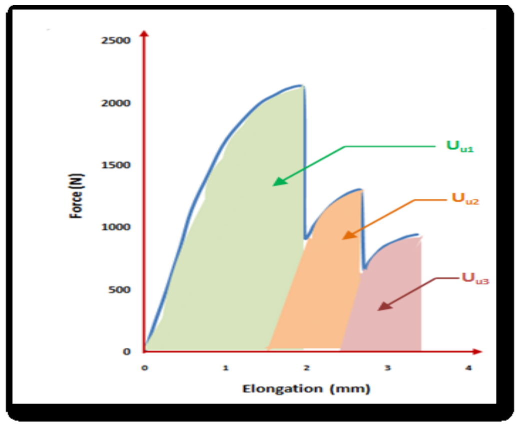

Figure 5. Strength-elongation diagram

The energy required to break a test piece is derived from the area under the tensile curve. The table will gather the energy calculated for each energy loss depending on number of broken wire.

Table 3. Values of residual ultimate energy

U_u	U_{ur1}	U_{ur2}	U_{ur3}
7,9	5,21	1,606	1,09
0	3/7	5/7	1

IV.2. Energy loss in static tensile

In order to normalize the residual energy, we consider the ratio Uur / Uu (residual ultimate energy dimensionless) depending on the life fraction of life β (ratio of the number of broken wires observed

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during the test on the total number of wires which is 7) as shown in Figure 6

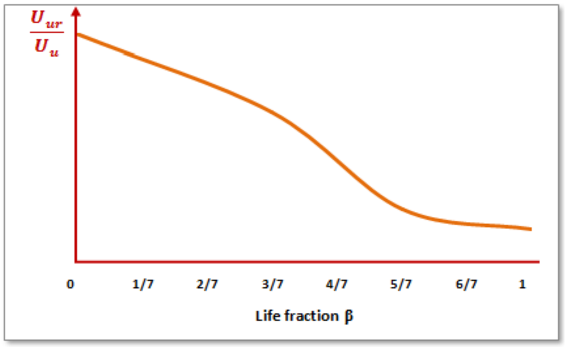

Figure 6. Energy loss in static tensile

These results show that the rate of energy loss is greatest at low to high level of damage. The wires break easily and faster in the strand after a certain level of damage.

IV.3.Calculation of static damage

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

$$Ds = \frac{1-\frac{Uur}{Uu}}{1-\frac{Ua}{Uu}} \quad (1)$$

Where:
Uu: the value of the total energy
Uur: the value of the residual ultimate energy
Ua: the energy just before the final break

Throughout the test, we are following the phenomenon of damage from the initial state to the complete rupture of the specimen by measuring the ultimate residual energy 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 Ds Equation (1) and presented in figure 7.

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

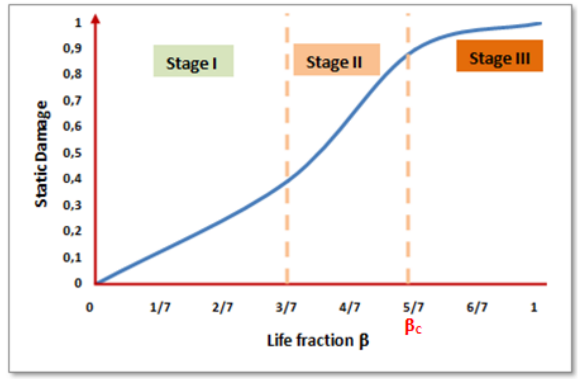

Figure 7. Evolution of the static damage depending on the life fractionβ

The increase of the damage means the loss in the stored energy; this loss is changing when the number of broken wire becomes more important.

From Figure 6, we could distinguish three stages:

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

The critical point is βc indicated in figure 6 which means that starting from 5/7 (71% of broken wires), the damage of strand that belongs to stage III becomes unstable. Thus, when these dimensionless ratios are reached, a predictive maintenance intervention is necessary and the strand is useless.

IV.4Calculation of damage using unified theory

The damage of the strand being progressive, its variation is influenced by the level of loading. Various representative

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theories of this damage are given initiated by the linear of Miner rule; finding that the damage changes linearly depending on the life fraction of life [10]

By analogy with the unified theory, an empirical relationship describing the damage is proposed:

$$D = \frac{\beta}{\beta + (1-\beta)\left[\frac{\delta - (\delta/\delta_u)^8}{\delta - 1}\right]} \quad (2)$$

Where: $\beta = \frac{N_i}{N_t}$, $\delta = \frac{U_{ur}}{U_0}$ and $\delta_u = \frac{U_u}{U_0}$

U0 is the residual endurance limit that could be determined by multiplying the ultimate residual energy by a coefficient α (for n = 0; U0 = α Uu).

For a coefficient $\alpha = \frac{1}{\text{Safety factor of the strand}}$

The variation of the damage according to β with δ as a parameter is shown in Figure 7.

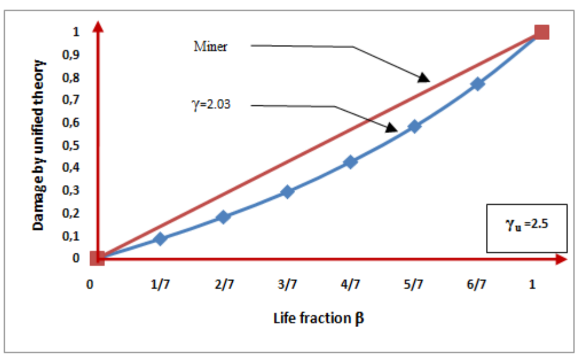

Figure 8. Evolution of Damage by unified theory and Miner law in function of the life fraction

The resulting curve is associated to a particular level of loading. This damage curve approaches the bisector (linear rule of Miner) depending on the life fraction β.

IV.5.Comparison between experimental and theoretical damage

The superposition of the damage curves obtained by the unified theory and that of residual energy and that of the linear Miner rule are illustrated in Figure 9:

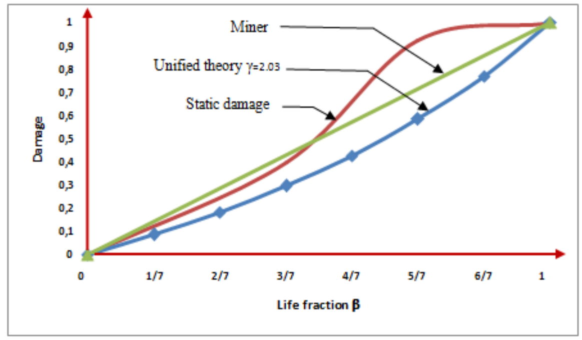

Figure 9. Comparison of theoretical damage according to the unified theory and Miner rule with static damage

The correlation between the theoretical values calculated from equation (2) and the experimental results of residual energy appears on the curves in Figure 9. We note that for stage I representing the initiation of damage, the three curves are similarand the difference between the theoretical and experimental curve increases gradually towards the end of stage II and stage III of damage.

V. Conclusion

In order to estimate the damage progression of a strand extracted from an antigiratory steel wire rope (19x7) without loss of time and expense, a study was carried out based on a simple static tensile test.

Subsequently, we could determine the different stages of strand damage (Stage I, which corresponds to the initiation of the damage, stage II: progressive damage and stage III brutal damage), these stages predict the critical life fraction (βc= 5/7). This intrinsic parameter of this type of strand defines the appropriate time for a predictive maintenance.

The difference between the theoretical curve obtained by the unified theory and the experimental curve increases gradually in stage II and stage III without being distant, which make the model of the unified theory not far from experimental reality.

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

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