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ANALYTICAL MODELING AND EXPERIMENTAL CHARACTERIZATION OF RESIDUAL RESISTANCE LOSS OF BROKEN WIRE ROPES LIFTING

Chouairi Asmâa[1] --- El Ghorba Mohamed[2] --- Benali Abdelkader[3] --- Boudlal El Mostapha[4] --- Hachim Abdelilah[5] --- El Had Khalid[6]

[1,2,3]*Laboratory of Control and Mechanical Characterization of Materials and of Structures, National School of electrical and mechanical, Hassan II University, Casablanca, Morocco*

[4,5,6]*Higher Institute of Maritime Studies, Department of Machinery, Hassan II University, Casablanca, Morocco*

ABSTRACT

The lifting wire ropes are hierarchically complex structures, very helpful and widespread in heavy manufacturing roofs, lifting systems, mining industry, offshore structure, electric lines, elevators, suspension bridges and transmission towers. Generally, the metallic cables structure provides solutions particularly interesting and spectacular to current problems faced by industries, which are called regularly to perform tasks for mechanical handling in steps of manufacturing product. The repetitive nature of these tasks, rather than decreasing the risk of accidents, helps to accentuate them by a sort of addiction to risk. In this context, the wire ropes are a prime target of brutal damage, compared to conventional structures. More generally; the sudden failure is the major cause of cables degradation. Industrial experience shows that the failure of much of their hoisting ropes in use is most commonly due to cumulative damage of wires. This is particularly insidious due to its hidden nature; it can lead to significant reduction in strength capacity of wire ropes over time, which can sometimes lead to their total or partial rupture. In order to optimize the residual resistance loss of a lifting wire rope, we propose a study of rupture impact of its wires on the loss of residual strength elastic. The results of tests allow a comparison between the loss of ultimate strength and residual strength loss residual elastic, so as to determine the normalized resistance and estimate the damage. The results of this work would be operated to establish the bond between reliability as being a statistical size and the damage by artificial damage observed and caused by cyclic requests.

Keywords: Lifting wire ropes, Brutal damage, Sudden failure, Degradation, Cumulative damage, Strength Capacity, Normalized resistance.

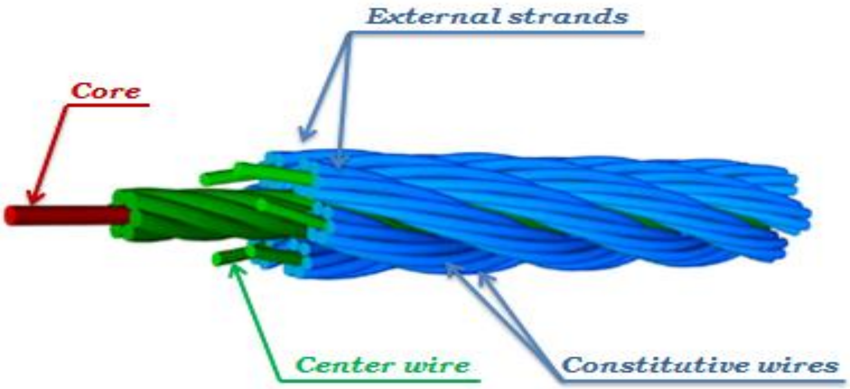
1. INTRODUCTION

Using cables as part tense has become widespread in recent decades. They consist of high strength wires which are gathered in packages so as to obtain the resistance traction desired.

A wire rope consists of many wires twisted together to make a complex structure combining axial strength and stiffness with flexibility under the bending action [1]. The producers of wire rope offer a wide range of rope types, in which the wires can be organized in according to different configuration for achieving an acceptable performance in a wide range of safety critical applications. These elements are long lasting when properly used and maintained.

The rope is constructed by laying several strands around a core (Figure 1). These strands have a central wire around which single metallic wires are helically wrapped.

Figure-1. Component parts of a metallic wire rope



The breaking cables by artificial damage are the process of cumulative damage caused by loads of varying and repeated intensity. The fatigue damage occurs only in regions of the cable which deform plastically under a load of varying intensity. After a number of fluctuations, causing cumulative damage initiation and propagation of cracks in plastically damaged regions.

The main cause of failure is associated to the wire of interfiled friction between layers along the wire, due to continued aggression of environment (effects of rain, wind) and changes in random loads [2]. When these movements are caused by stress variables, it concerns interfiled friction or friction induced by small displacements [3]. This is exacerbated in areas of stress concentration by phenomena of wear, fatigue or corrosion, which are direct consequences of the modifications strong geometrical and mechanical characteristics of components [4]. Indeed, the detection of thread broken internal or external is of extreme importance. However the situation may be complicated by multiple cuts that occur along the wire especially in the presence of friction interfiled.

2. FAILURE PROCESS OF METALLIC CABLES

The sudden failure of cables most often results from interactions between two wires in contact subjected to relative displacements of low or high amplitude. Several phases can be distinguished in the fracture behavior of a cable. During the first part, a more or less important degradation of wires with rapid formation of wears debris is ejected from the contact. During the second phase, we note the appearance of microcracks, initiated at contacts involved in the formation of larger debris accentuating degradation wire. The last phase corresponds to crack propagation toughness of contact when the cable reaches a critical value.

Contact materials reduce the wear of wires cable and their cracking is the wear materials such as zinc or the aluminum alloy and materials lubricants such as high density polyethylene. Studies by Urvoy [5] were used to compare the change in wet-on galvanized wires. Mechanical stresses at the contacts interfiled subjected to friction between wires. These tests demonstrate that the fatigue endurance limit 100 MPa ($\Delta\sigma$ ridges / peaks) obtained by Siegert and Brevet [4] on uncoated dry wire is raised to 170 MPa for dry galvanized wire at 200 MPa for uncoated lubricated wire. Hobbs and Raoof [6], underlined the importance of the nature of contact between wires on the severity of the phenomenon. For them, the contact stresses are even stronger when the contact area is small, which explains the location of ruptures on contacts. Raoof studied the distribution of Von Mises stresses in the wires of two successive layers in point contact with friction [7]. By combining its results with existing experimental data on the fatigue of an individual wire, it offers a model to predict the lifetime of the cable under cyclic axial loading.

Meksem [8], developed an analytical model to analyze the mechanical behavior of lifting wire ropes with different percentages of broken wires subjected to tension and fatigue. The model developed determine the reliability of a cable degraded at different levels of damage and the corresponding maximum tensile strength, to help in the planning and organization of preventive maintenance. Chouairi, et al. [9], optimized the relation reliability-maintainability and availability of metallic wire ropes, an extensive analytical modeling study has been performed in order to estimate the reliability-related to damage in the case of mixed systems, series-parallel or parallel-series configuration with symmetrical applied.

3. LOSS OF ELASTIC AND ULTIME STRENGTH IN STATIC TENSILE

In our study, we will look at tests to be performed on cables of type 19 * 7 (7 wires 19 strands) of non-rotating structures (1*7 + 6*7 + 12*7) 6 mm in diameter, composed of steel light greased, metal core, right cross, preformed, used especially in tower cranes and suspension bridges.

Table-1. Main features of the experimental rope study

Cable diameter (mm)	$D_c = 6$ mm
Design	19*7 (1 * 7 + 6 * 7 + 12 * 7)
Nature and direction of wiring	Steel, ordinary lay on the right
Minimum breaking strength	23,2 KN
Surface quality of the wires	Galvanized steel
Twisting direction	Right
Mass per unit length (kg/m)	0,153 kg/m
Use	Lifting and handling
Young modulus of the wire (MPa)	E = 200 000 MPa
Poisson's ratio	$\nu = 0{,}3$

They are composed of two layers of strands wired in opposite directions, which avoids the rotation of the suspended load when the lift height is important and that the burden is not guided. Their use requires a certain amount of caution at rest and during operation. This construction, robust nature, is widely used for common applications and especially for lifting heights reduced.

The length of the sample of the cable is equal to 10 times the pitch of "réancrage" more 20 mm necessary for the mooring. Therefore, the length of 700 mm was taken as the length of trials for these cables. The measurement accuracy is in length ± one millimeter for all samples studied (Table 1). The thread was broken artificially created in the cables with a power saw (Figure 2). A "détoronnage" of the cable is required to break a number of threads in a layer. Characterization tests are started on test blank, and then on other damaged artificially with an electric saw.

Figure-2. Tensile test for a damaged cable at 30% of broken thread

a) before tensile test b) after tensile test

The damage consists in breaking the thread samples constituent at different percentage. Why the samples are divided into four batches each consisting of six specimens. The first batch of specimens damaged to 30% (30% of the thread constituting the specimen are disrupted artificially). The specimens of the other three lots are damaged respectively 50%, 70% and 90% (Table 2).

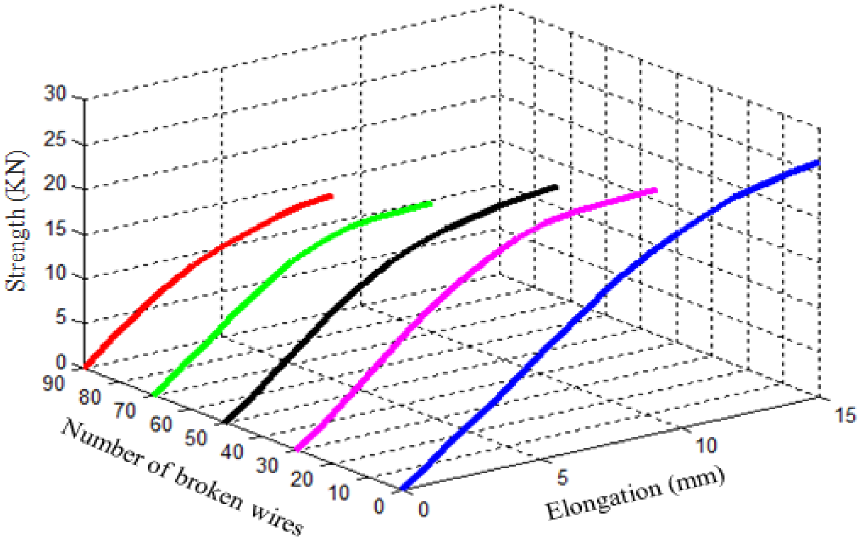
4. RESULTS AND RECOUNTS

4.1. Static Tensile Test on Degraded Cables (19*7)

Recall that our goal is to calculate the damage elastic and ultimate through the unified theory and compare the results of damages to quantify the energy reserve between the two types of damage. The curves of experimental trials of force in function of the elongation for cables at different number of broken thread are given in the (Figure 3) relatively to the cable of 6 mm.

A virgin cable has a residual ultimate force of 26, 35 KN which fall gradually, as and when extent, that the number of thread broken increases, until the value of 13 KN, for a cable 90% of thread broken.

Figure-3. Comparison of stress-strain curves at different levels of degradation of cable with different number of broken thread



For broken wires at 30%, 50% and 70%, the maximum force of break successively diminished from 20 KN to 17,50 KN and 14,33 KN at the end; this can be translated into a loss of resistance of the cable depending on number of thread broken (Figure 3).

4.2. Calculation of the Conventional Force and the Standardized Section of the Cable (19 * 7)

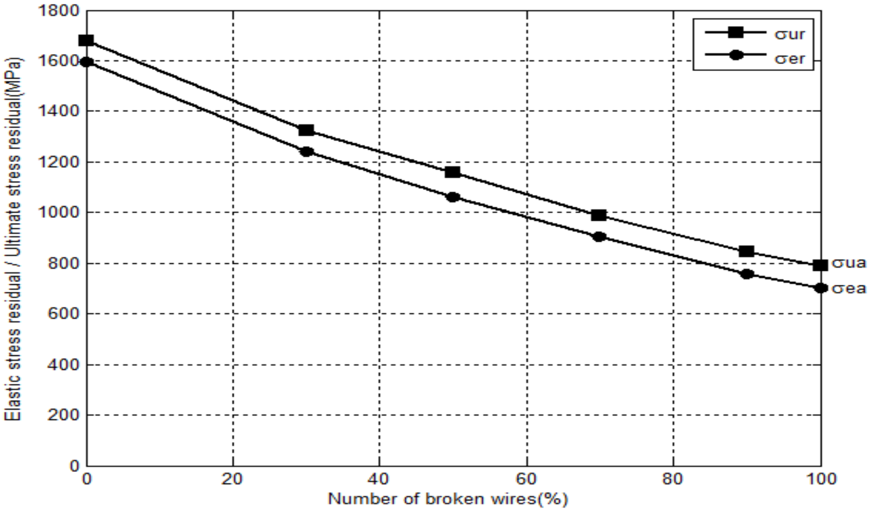
According to the tensile curves of broken cables at different levels of degradation (Figure 3) we calculate the ultimate strength and the elastic strength conventional, and then we determine the standardized section to derive the residual stress of the cable studied (19 * 7).

4.3. Loss of Residual Strength According to the Number of Broken Wires

The experimental results are shown in figure 4. This figure shows the change of the loss of tensile strength as a function of number of broken thread.

The cable has an ultimate tensile strength of 1680 MPa and static yield strength of 1593MPa. The yield of residual degrades continuously as the number of cyclic loading amplitude σ_e believed to failure. Furthermore, we note that the two curves have a decreasing pace, depending on the level of constraint imposed only for a number of relatively large broken threads (Figure 4).

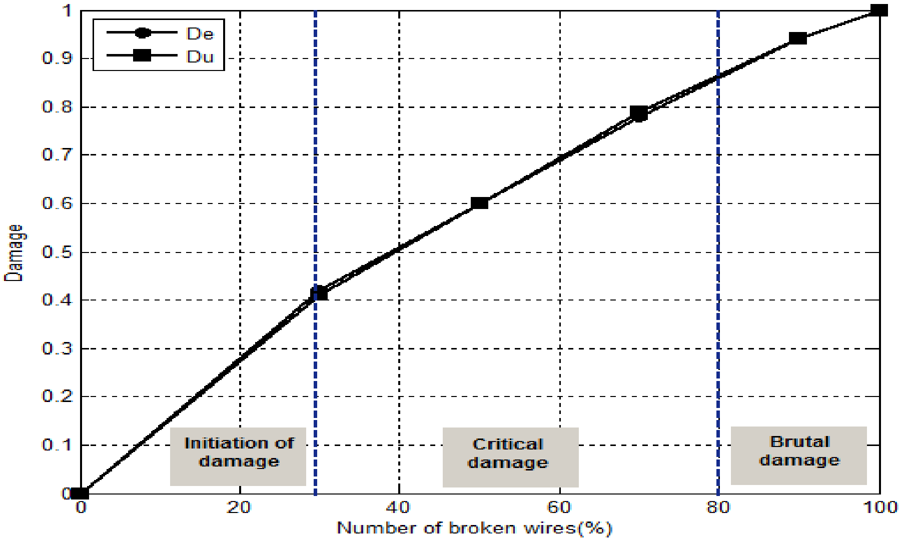
Figure-4. Loss of residual strength based on the number of broken thread of the cable diameter 6 mm



5. DAMAGE OF THE WIRE ROPE (19 * 7)

The damage to the number of broken thread is given in Figure 5. Each curve is associated with the elastic stress or ultimate applied. This damage is dependent on the level of number of damaged thread.

Figure-5. Cumulative Damage artificially damaged specimens



From Figure 5, in the presence of accidental damage, there are three areas. Zone 1 corresponds to the initiation of the damage zone 2 which corresponds to critical damage and area 3 which corresponds to the brutal damage. We deduce therefore, that in optimum conditions of use, wire rope hoist should be inspected regularly and at short intervals from 30% of its life. Therefore removal becomes mandatory from 80% of its life.

However accidentally damaged cable must be inspected immediately and follow up standing in case of further use.

6. CONCLUSION

Cables are often fundamental to the maintenance of structures and the safety of users depends on their condition. This security is directly related to the ability to monitor and detect their degradation. The comparative results between the elastic and residual damage show a good match between the two curves. The analytical results indicate a satisfactory agreement with experimental results for the cable type studied. This comparison shows the validity, relevance and reliability of the analytical model for the characterization of elastic cables.

The results of premature rupture of wires on hoisting ropes strongly solicited showed that a significant decrease related to the length of service. The number of broken wires is practically an important parameter for the decay rate of the damage.

Similarly, our experimental study comparing two types of wire rope hoist damage, mainly the ultimate damage and the elastic one. The results show a loss of residual strength in both cases but more pronounced in the elastic damage. Cable artificial damage is unsafe due to normal use, fatigue, corrosion or wear.

Wire ropes for lifting must be regularly maintained, the type of maintenance depends on the class of the lifting device, its use and the type of cable. It should be noted that regular maintenance greatly increases the service life of wire rope hoist.

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