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Failure of PC Wire for PCC PIPES due to Corrosion in Man-made River Project Investigation of Possible Causes and Relation of Wire Breaks with Potential Measurement

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ABSTRACT

Pre-stressed wire is considered the most important in manufacturing pre-stressed concrete pipes, this is because the life of the mentioned pipes depends on the integrity of the wire. When the wire wrapped around the concrete core, it provides a compressive strength which enable the concrete cores to withstand the internal and external pressures. Since LIBYA has constructed different stages of man- made river project using the pre- stressed concrete pipes, in different diameters (1.6, 2.2, 3.6 and 4.0 m) to transport water from the south part of the country to the north populated area, pipe failures due to corrosion have been occurred after several years of operation at different locations of pipeline route. The PC wire corroded and at the end breaks and become unable to withstand internal water pressure. The wire breaks recorded using hydro phone technique added extra pressures on the project management staff and engineers, to resolve and study the possible main cause of wire break and pipe failure. Information regarding the PC wire used will be provided in this paper which include specification, manufacturing etc. In this paper, causes of wire corrosion and wire breaks after several years of PCCP operation will be discussed and explained, in addition to that, correlation between wire breaks and pipe potential will be addressed and highlighted.

Keywords: wire technical specification - wire break – corrosion causes - potential measurement – failure.

INTRODUCTION

The pre-stressed wire considered to be the main material in the production of pre-stressed concrete cylinder pipes, ($PCCP_s$) when is wrapped around the concrete core introduces compressive strength which sustain the internal and external pressure.

Man-made river project, Libya constructed different phases using the "4" meters diameter PCC Pipe which extended to the thousands of kilometers to transports the water from the Libyan south Sahara to the dense populated areas in the north part of the country. After several years of operation, a number of pipes failures were recorded due to pre-stressed wire corrosion. After that, all precaution was taken such as protection of pipe lines using cathodic protection and hydro-phone technique wave installed to record any wire breaks. In fact, the cathodic protection system worked to delay wire corrosion for more than (18) years before another pipes collapse. Also numbers of pipe start to record a wire break some of them reach more than (100) wire break.

A discussion was taken to study and review all concern regarding the pre-stressed wire, which not limited to its chemical composition, its manufacturing process, transportation and storage but also the effect of stress applied during wrapping the wire around the concrete core and the relation between potential measurement and numbers of wire breaks.

Pre-stressed wire chemical composition: - Table (1) shows three options for wire chemical composition.

lament percent	1st Option	2nd Option	3rd Option
	Carbon steel	**Vanadium addition**	**Chromium addition**
C	0.8 – 0.84	0.79 – 0.83	0.76 – 0.80
MN	0.85 – 1.00	0.75 – 0.90	0.60 – 0.90
S	0.030 max	0.030 max	0.030 max
P	0.035 max	0.040 max	0.040 max
Si	0.20 – 0.35	0.50 max	0.20 – 0.35
V	-	0.05 – 0.09	-
Cr	-	-	0.20 – 0.30

Table (1): Pre-stressed wire chemical composition

Man-made river project consultant chooses the 1st options during the early stages of PCCP production with carbon percent between 0.80 – 0.84, the iron-iron carbide phase diagram shows that from 0.77% up to 2.11% carbon, is hyper-eutectoid portion of the Fe-Fe_3C. That is mean the raw wire (9 to 12mm) micro structure from which the pre-stressed wire manufactured is cementite, (Fe_3C.) at the grain boundary of the pearlite grain and it's very hard chemical component, extremely brittle and its hardness reaches 800 Kg/mm^2. In this chemical component (cementite), the percentage of carbon reaches 6.67% and it's the max percentage of carbon which dissolved in iron.

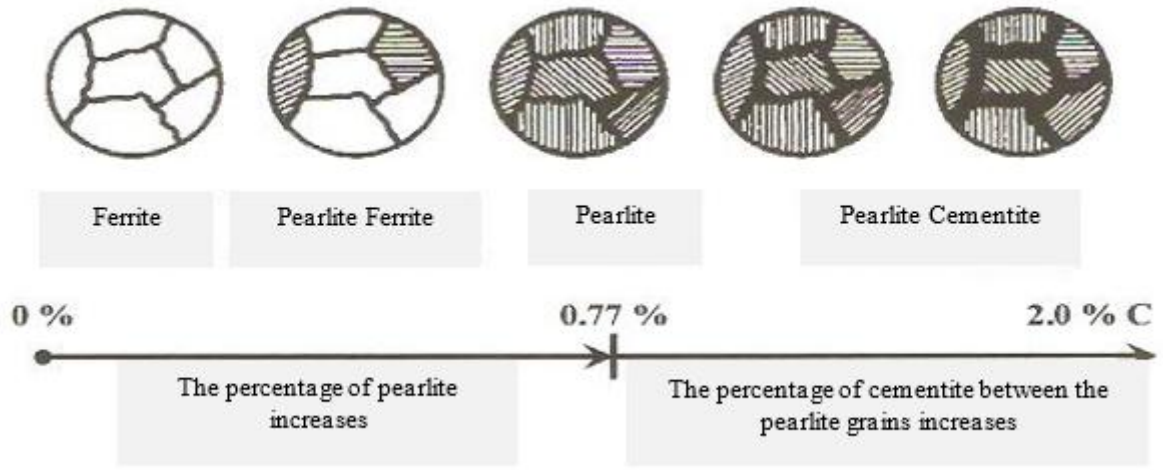

Fig. (1): Show the effect of carbon percentage on the steel micro structure.

This prove that the mechanical properties for cementite dominate and control the nature of the break and collapse, it will be preferred site to start, spread the cracks. This could be one of the possible cause which contributes to wire break.

Raw wire pickling and baking processes: - Pickling using HCL, is a method of cleaning rusty and greasy raw wire (9-12mm) coils and this is a chemical reaction process, accompanied by the release of hydrogen, which penetrate into the metal structure and increase the tendency for hydrogen embrittlement. Baking process used to release the hydrogen which penetrates during pickling. Backing temperature usually maintained between (200-300°F) for a known period of time.

Raw wire **Pickling path** **Pickling process**

Fig. (2): Shows raw wire, pickling bath and pickling process.

Now the question is, what is the efficiency of this process for releasing hydrogen? and does it release all the penetrated hydrogen? This could be one of the possible reason that contribute for wire breakage.

Raw wire cold drawing process: - This process to reduce the raw wire of (9-12mm) diameter by bulling it through different dies to the required pre-stressed wire diameter (4.88, 6.35 and 7.25mm). Welding the ends of pervious draw coils with a new one, and the possibility of not excluding marked weld area could be happened before packaging the pre-stressed wire coils, weld area good site for wire break.

Pre-stressed concrete cylinder pipe manufacturing plant: - In the pipe manufacturing plant and from. The experience gained all the precaution should be taken to confirm that all material, especially pre-stressed wire which can corrode or breaks are fully controlled, by eliminate and prevent the followings: -

- Using pre-stressed wire damaged by sea water during transportation by ships.
- Using dissimilar metal to splicing the pre-stressed wire coils together.
- Never use of dissimilar metal of electric bonding strap in contact with pre-stressed wire.
- Wrapping the pre-stressed wire during either sand storm (sand blown material with high salt content will stick to the slurry which coat the wire), and heavy rain which will wash out the slurry coat and enhance wire corrosion.

Pre- stressed wire failure: - Man-made river project use three different diameter of pre- stressed wire (4.88mm, 6.35mm and 7.25mm) according to the pipes design. During wrapping the wire around concrete core in pipes manufacturing plant, the wrapping stress reaches (1142Mpa, 1242Mpa and 1304Mpa) respectively. The wire break under the mentioned wrapping stresses were observed many time and the fracture shape was cup and cone, which explain that the wire elongated and exceeds ultimate tensile strength. This makes us to believe that, the pre- stressed wire in many produced concrete cylinder pipes becomes ready to break. See Fig. (3) shows ductile fracture in pre-stressed wire, Fig. (4) shows the stress strain curve for pre-stressed wire.

Fig. (3): Shows pre-stressed wire ductile fracture for burst pipe

1180 -

1100 -

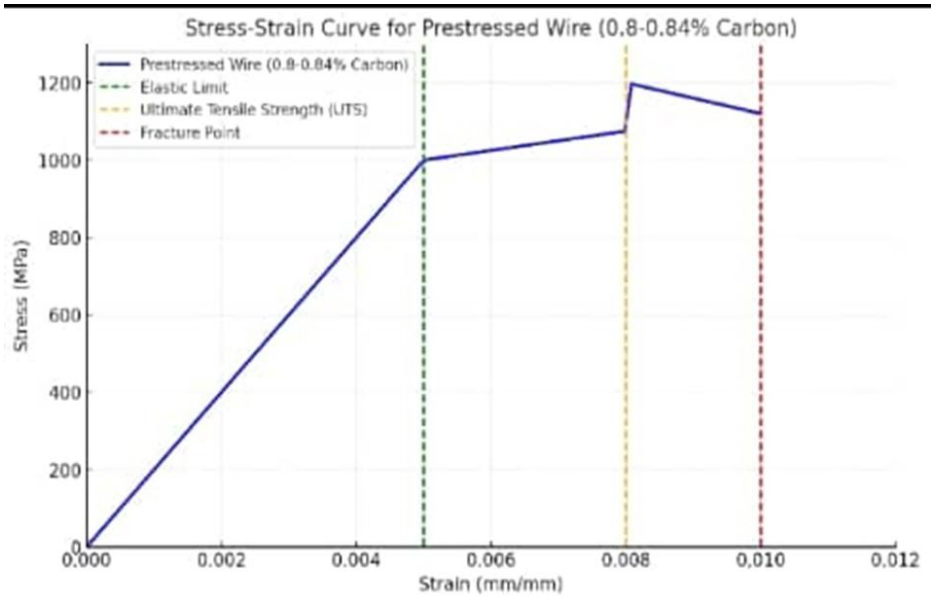

Fig (4) shows the stress strain curve for pre-stressed wire

Relation between wire breaks and decay potential: - The durability of PCC Pipes depends on whether the cathodic protection was implemented on sound or unsound pipes. Man-made river project pre-stressed concrete cylinder pipes, protected using sacrificial cathodic protection system. The acoustic technique (hydrophone) used to record wire breaks, this was done after (10) years of operation and a number of pipe bursting. It is difficult for the said technique to determine the accurate number and exact location of broken wire and also failed to detect any leaks. Based on achieving the decay potential of (- 100mV) criteria, which is approved and used in Man-made river project as specified by international specifications and standers (i. e NACE). The efficiency of cathodic protection system were evaluated. Excessively high potential can lead to hydrogen embrittlement especially in pre-stressing wire in chloride - containing environment, result in weakens the wires, reducing their mechanical load - carrying capacity and increase the likelihood of breakage. This could not occur as the PCC Pipes protected cathodicaly using sacrificial anodes.

Low potential may not provide sufficient protection allowing the corrosion to continue, gradual corrosion reduces the diameter and strength of wires, increasing the possibility of breakage. Broken wire may concentrate current at specific areas leading to non-uniform protection this could accelerate localized corrosion of surrounding intact wires. When cathodic protection potential is properly controlled the corrosion is slowed or halted.

Table No. (2): present data for wire break and achieved decay potential for one long pre- stressed concrete cylinder pipe line named, (SASS). The below curve will illustrate the relation between recorded wire break and decay potential.

No	Pipe I.D No & Station No.	White (W) or Black (B) Pipe	Numbers of Wire Break	Average decay Potential (- mV)	Year	Remark
1	210+520 - D64	W	96	34	2020	SA/SS LINE
2	211+520 - D16	W	77	146		
3	300+000 - D0	B	116	188		
4	305+440 - D12	W	47	157		
5	314+300 - D1	B	67	130		
6	231+510 - D0	W	25	78		
7	334+240 - D0	B	63	169		

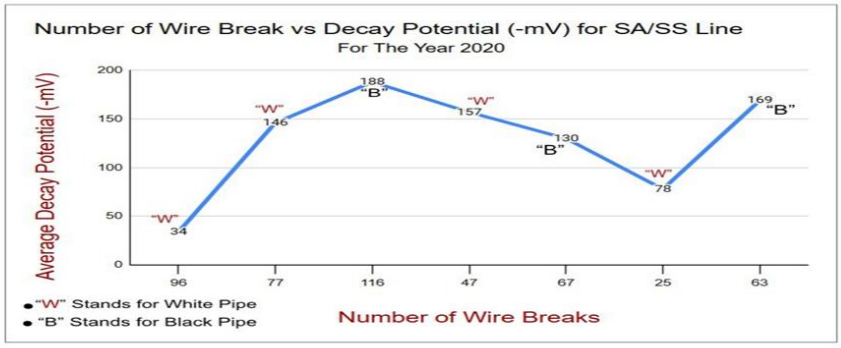

Table No. (2): present data for wire break and achieved decay potential

DISCUSSION AND CONCLUSION: -

- It is known that the in pre-stressed concrete cylinder pipes, the pre-stressed wires are the main controller of pipes age life, when its corroded, relaxed or broken becomes unable to withstand water internal pressure. Many factors which are presented in this paper affect the pre-stressed wire stability and safety. The pre-stressed wire produced using chemical composition of 1st option in table (1), with (0.80 to 0.84%) carbon, result in micro structure of pearlite grain surrounded by cementite which is preferred site for the occurrence and spread of cracks, the cementite also classified as extremely brittle.
- The question is still valid regarding the measure of hydrogen penetrates to the raw wire during pickling process. The Japanese invertors Nakamaru Hiroki, Fujita Sakea and Tsuru Toru invented a method in year 2010 to measure the amount of hydrogen penetrate to the metal surface during corrosion process Man-made river project started to import the pre-stressed wires coils in middle of 1986, before the date of this invention.
- The pre-stressed wire deformation not related only to the applied load, because if you apply some load to different wire diameter, area and length you would get different deformation. HOOKES law: the force is proportional to the extension.
- (Fig. 4) shows stress-stain relationship for pre-stressed wire with a carbon percent of (0.8-0.84 %), same as 1st option in table (1) which selected by Man-made river project consultant.
  Beyond elastic limit (green dashed line) the wire experiences permanent deformation. The linear portion of the curve corresponds to hookes low, where stress is directly proportional to strain. **Ultimate tensile strength (UTS)** "yellow dashed line". The maximum stress the material can endure before necking. At this point the wire reach its peak load-bearing capacity. Beyond the UTS, the material begins to weaken, it may still elongate before failure.
  Fracture point (red line). The point where the material fails and fractures, the material has undergone significant strain. The wrapping stress used to wrap the Man-made river project pre-stressed concrete pipes are very close to the (UTS) show in Fig. (4). In some case and even more when reaches (1242Mpa) and (1304Mpa) in other case. That means these stress made the wire to pass (UTS) and no safety factor was taken to operate below ultimate tensile strength.

- It is important to understand the correlation between the decay potential and wire breaks because it provides critical insights into the health and performance of (CP) system, as well as the overall integrity of the structure being protected.
  In the SA/SS line chart, there appears to be a non-linear correlation between the number of wire breaks and the decay potential. The decay potential does not increase or decrease steadily with the number of wire breaks. A significant rise in decay potential is observed between wire break of (96) and (116), peaking at (188mV) for (116) wire break. A decline follows, dropping to (78mV) at (25) wire breaks. Again to (169mV) at (63) wire breaks inconsistency in behavior. A significant drop is seen at (25) wire breaks, which indicate an anomaly or a specific influencing factor.
- The relationship between wire breaks and decay potential could suggest that the material is deteriorated (higher decay might indicate increased corrosion).
- Section with low decay potential but many wire breaks might indicate CP system failure or mechanical issue.

Recommendation: -

- Improve the mechanical properties of steel with an increase of ductility and toughness, this process transforms the structure of pearlite lamellar to a small spherical shape in ferrite matrix.
- Reduce the immersion time of raw wire in HCL tank.
- Use inhibitors to reduce hydrogen emission.
- Option No. (3) with (0.76-0.80) carbon percent and chromium (Cr) addition of (0.20-0.30%) will prevent the formation of cementite.
- Eliminate using damaged pre-stressed wire by sea water.
- Prevent using dissimilar metal to splice the pre-stressed wire.
- Stop wrapping the pre-stressed wire during either sand storm and heavy rain.
- Regularly monitor the decay potential to ensure it remains within the optimal range for protection by using the appropriate monitoring techniques.
- In practical applications, the wires must be wrapped around the concrete core with a safety stress that does not reach dangerous reduction in area and necking of the wires.

REFERENCES: -

[1] Introduction to physical metallurgy. 2Ed Jan. 1997. Sidney H. Avner.
[2] Strength of materials, 6Th edition by John Cace 2001 – 2002.
[3] Callister, W. D & Rethwisch, D.G. Material Science and engineering: an introduction. 10Th edition wiley 2018.
[4] Peabody's "control of pipe line corrosion" (2Nd edition).
[5] Measuring of hydrogen intrusion surface by Inventor Nakmaru Hiroki, Fujita Sarea and Tsuru Torn, JAPAN 26/FEB./2010.
[6] A primary proposal to study the causes of wire beak in pre- stressed concrete cylinder pipes in Man- made river project May 2005: Saad A. Bakheet and Salah M. Elkoum.
[7] NACE (national association of corrosion engineers) standards for cathodic protection system.