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FINDING PERCENTAGE OF BREAKDOWN STIMULATION OF ALUMINUM WIRES THAT OPERATES IN A CORROSIVE MEDIUM

Mohammed Abdulateef Ahmed

Production Engineering and Metallurgy , University of Technology ,Baghdad, Iraq

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Abstract: The study of the duration of mechanical resistance to static tensile stress (withstand time) for an aluminum wire that being suffers from the corrosion effect stimulated by stray currents at different temperatures. Test device was designed and produced locally "in advance" in accordance with the specification (ASTM G103 - 97) to create static tensile stress of (1 N) on an aluminum wire of type ASTM (B231/B231M) with particular dimensions and utilized in the transmission of electrical energy, and when the wire is surrounded by a corrosive environment (NaCl solution) (3.5 % NaCl) at three different temperatures (25, 50, and 75 ° C) without any external electrical current causing corrosion; this symbolizes stray currents. Then compare the findings of that example to the results of the same wire's withstand time in the presence of an external electrical current generated by corrosion of type (D.C) by (5V & 3A).
Following that, the resulting diagrams were analyzed, and it was discovered that the wire resistivity time (without the existence of stray currents and at a temperature of 25 ° C) completed (17 days), which is the longest duration of endure, and the lowest time of resistivity or resistance period (in the existence of an external electric current) is (18 hr.).Impact of (stray currents) at (75 ° C), and this is an indicator of the stray currents with corrosive environment temperatures on the resistance period (withstand duration) in the existence of static stress. The total stimulation increase is 1.9% between corrosion at 75°C and 25°C.

Keywords: *Percentage, stress corrosion, pitting corrosion, stray currents, breakdown stimulation.*

1. Introduction

The mechanical resistance of metals is an essential feature of mechanical parts that operating under the influence of stress, even if the stress is static, that is, under constant loads, and the mechanical resistance of metal parts begins from the surfaces, as mechanical cracks begin from the metals' surfaces; and surface cracks are places of stress concentration and gathering. The failure of the metallic part of the surface starts at the surface and develops to the center of the metallic mechanical part [1] [2].

Corrosion is a type of electrochemical or chemical damage which influences metal surfaces. It is a chemical failure that leads to the disintegration of metallic mechanical parts and also begins from the surfaces of metals. Chemical corrosion is defined as the extinction or collapse of metal components as a result of their interaction with the surrounding corrosive environment in the existence of anode and cathode electrodes, an electrolyte, and an electrical cycle. There are several types of chemical corrosion. The classification of corrosive environment based on humidity

**Corresponding Author*: asst.prof.mohammed@gmail.com

comprises dry corrosion that happens at high temperatures, and wet corrosion that happens at room temperatures. A classification based on the shape or location of the corrosion, which is divided into two types: general or uniform corrosion and local corrosion. It has various shapes, comprising selective, pitting, interstitial, galvanic, biological, knife-edge, crevice, filiform, stress corrosion cracking, and other shapes of localized corrosion [3]. Definitely, corrosion of all types happens within the following chemical equation (1), which clarifies that the metal decomposes into metal ions, leaving behind spaces as centers of stress and failure [3]:

$$M \rightarrow M^{+n} + ne^{-} \tag{1}$$

It is important to note that corrosion causes large material and economic losses, damage to materials and components. Damages that are not limited to few lines, which causes sudden stops for factories, followed by economic losses, and corrosion damage to canned products in metal cans. Corrosion damage may cause physical and human harm, particularly in the areas of big steam boilers, chemical treatment plants, electric power generating and transmission places, and ground with air transmission lines [4][5].

Mechanical cracking with corrosion, also known as stress corrosion cracking, occurs in mechanical metal components, which are exposed to loads even when they are static in the existence of a corrosive environment. It has greater impact on those components, and it cannot be ignored, when there are other additional effects that boost and activate it, such as temperature increase and change in the concentration of the corrosion environment, as well as the existence of an external electrical current that activates and boosts corrosion. This is something appears all the time in factories and labs, when loads are applied in conjunction with the existence of corrosive environment that surrounding metal mechanical components. In the existence of a corrosive environment, stress corrosion cracking shows as cracks and microscopic cracks on the metal's surface, which they expand progressively and spreading directions towards the metal's center. This failure happens unexpectedly and treacherously, since it happens and grows fast, particularly when increasing and stimulated elements are present on the surfaces of ductile metals and alloys, such as aluminum, low carbon steel, and others [6]. When heavy loads are applied in the presence of corrosive environment, stress corrosion cracking caused by electrical currents (stray current) is visible in pipes, transmission rails, and electrical wires. These stray electrical currents are caused by improperly bonded electricity supply sources, stray currents from cathodic and anodic protection, or currents caused by electrical induction of big electrical equipment plugs [7][8].

These stray currents will turn the loaded metal mechanical component into a positive electrode and cause it to corrode more quickly (synergy), resulting in stress corrosion cracking. The catalyst is activated by stray currents and intensifies at high temperatures, as the load or tensile tension, even if static, will create cracks or micro cracks. After a significant amount of time has elapsed, and in the existence of a corrosive environment that will break through those micro-fissures, which unleash the metal's ions into the corrosive environment, leaving those ions unleashed behind them are cavities. These cavities serve as a source for stresses and cracks, and they are advanced, which in the presence of stray currents, the excretion of metal ions will result in more and larger cavities and cracks, because the metal is more anodic and energetic than it is used to be. Its energy is greater, it is essential to unleash metal ions to achieve stability, and this process of tensile stress and increased chemical corrosion continues with stray currents, until the metal collapses, particularly at high temperatures [9][10][11].

The percentage of stimulation due to stray currents (SSC%) was calculated from classic mathematical equation for percentages for many magnitudes as mathematical formula (1)[12]. To know the percentage of stimulation due to stray currents, it is essential to know the duration of the withstand or resistance of the wires which operates in corrosive mediums and to find the difference between the periods of withstand or resistance in those mediums like in the following mathematical formula:

$$S.S.C\% = \frac{D.P1-D.P2}{D.P1} * 100\%] \text{ at specified temperature } (1)$$

S.S.C% : Percentage of stimulation due to stray currents at specified temperature.

D.P1 : Durability duration without stray currents in (hr.) .

D.P2 : Durability duration with stray currents in (hr.) .

The aim of the research: Finding percentage of breakdown stimulation of aluminum wires that operates in a corrosive medium at specified temperature. The study's goal is to investigate static stress corrosion cracking in aluminum wires carrying electric current at different temperatures with and without stray currents in a laboratory setting.

2. Experimental work

2.1. Preparation of the test wires

Test wires, that are aluminum electrical wires of type ASTM (B231/B231M-16)[13] or ANSI H35.1/H35.1M [14] that are used in electrical current transmission cables, are cut, and their standard specifications are provided in Table1, and the utilized test wires are (45 cm) long and (1.5 mm) in diameter, as shown in Figure1. The chemical composition of the tested wires was illustrated in Table 2.

Table1. The standard specifications for ASTM (B231/B 231M).

Specification	Amount	Unit
Tensile strength	139.92	kN/mm^2
Modulus of elasticity	75.5	kN/mm^2
Thermal Elongation Coefficient	19.2	10-6 / °C
Electrical resistance at 20 ° C	0.07191	Ohms/km

Figure1. Shows the electrical tested wires type aluminum ASTM (B231/B231M -16) [13]**.**

Table 2. Chemical composition of tested aluminum wire.

Element	Amount
Al	99.57
Si	0.06
Cu	0.03
Fe	0. 29
Mn	0.01

Zn	0.04

2.2. Preparation of the Test Solution

The test solution that is used, is (3.5 % NaCl) and it is a solution containing chlorine ions (chloride), which is one of the most damaging ions for aluminum alloys, and it is utilized at various testing temperatures (25, 50, and 75 ° C) by heating it with an electric strip heater.

2.3. Description of the Test Device and its Configuration

The device is developed and made in accordance with American standards (ASTM G103 - 97) [15], as seen in Figure2. It consists of a glass test container filled with the corrosive solution and enclosed by an electrical heater strip, with two opposing holes closed with two rubber plugs and the test wire linked to the mechanical arm from the top. The arm is loaded with a variable weight from the other side. To guarantee equal weights on both sides, the arm contains a level gauge from the top, and the second end of the test wire is linked from the bottom to the balancing screw at the device's base, which the test wire is electrically connected to the positive pole. There is a tungsten metal rod, which is attached to the negative electrode, the tungsten rod passes from a side opening into the glass container that is filled with the corrosive environment, so that this rod is near from the test wire surrounded by the corrosive environment to ease the transfer of stray electrical currents. Another side hole allows the mercury thermometer to observe the temperature of the test medium. The device's body is manufactured of steel and has dimensions of (55 x 45 x 60 cm^3), and the utilized loads may be adjusted depending on the test circumstances. The electric current utilized is (5V and 3A) when an electrical transformer of the (DC) type is used. These details are shown in the schematic figure3.

2.4 Collecting results, plotting and analyzing data

Following completion of the planned experiments and collection of the results that achieved in scheduled form to be studied, analyzed, graphed, and compared with each other, to realize the impact of each variable on the path of laboratory experiments. Then, record the results of the discussion and comparing them with previous research within this field, or approach it to achieve scientific conclusions. To find the percentage of stimulation, it must use the mathematical equation (1), as following:

$S.S.C\%1 = 408 - 46/408 * 100\% = 88.73\%$ at 25°C

$S.S.C\%2 = 288 - 32/288 * 100\% = 88.90\%$ at 50°C

$S.S.C\%3 = 192 - 18/192 * 100\% = 90.63\%$ at 75°C

Figure 2. Illustrated the static stress corrosion cracking device that designed and manufactured locally according to the American Standard (ASTM G103 - 97) [15].

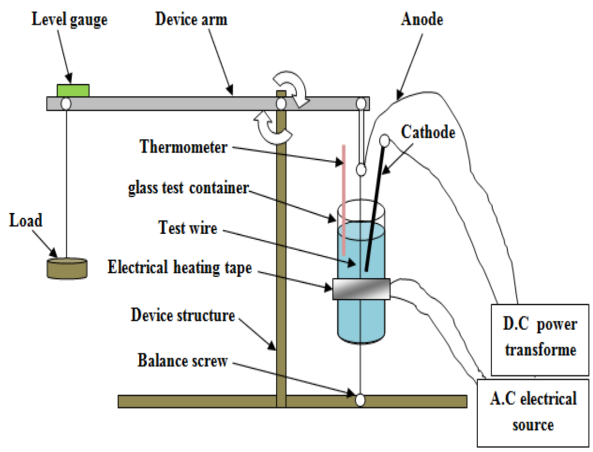

Figure 3. Illustrated a diagram of the static stress corrosion cracking device parts that designed and manufactured locally according to the American Standard (ASTM G103 – 97) [15].

3. Results and Discussion

Table3 and the figure in Figure4 & Figure5 demonstrate that there are two elements influencing the duration of mechanical resistance or the withstand period of aluminum wires working in corrosive environment under the effect of static tensile stress:

3.1. The Effect of Temperature of the Corrosive Medium

In both cases, for static mechanical stress in corrosive environment with or without stray currents, an increase in the temperature of the corrosive medium motivates the progression of pitting that caused by corrosion on the surface of the aluminum wires, resulting in a decrease in the durability of the aluminum wires. Without stray currents, the aluminum wire has a durability duration of (408 hr.) at a temperature of (25 °C), and a durability duration of (288 hr.) at a temperature of (50 °C), and finally, it decreases to become (192 hr.) at a temperature of (75 °C). However, due to the stray currents effect, rising in temperature for the corrosive environment, leads to a considerable rise in pitting corrosion, where the durability duration of aluminum wires is (46 hr.) at (25°C) and decreases to (32 hr.) at (50°C) to become (18 hr.) at (75°C).As a result of the boosting of pitting corrosion in this corrosive medium that contains chlorine ions (chloride) upon increasing its temperature, the high temperature of the corrosive environment will increase the rate of corrosion, boost the collapse of the wire, and decrease its durability, as mentioned in the research [6][7].

3.2. The influence of stray currents

Pitting corrosion occurs in the existence of stray currents and is considerably enhanced, particularly at high corrosive environment temperatures. Whereas at (25°C) temperature, the durability duration of wire was (408 hr.) in the absence of stray currents and (46 hr.) in the existence of stray currents. While at a temperature of (50 °C), the durability duration of wire decreases to (288 hr.) in the absence of stray currents and (32 hr.) in the existence of stray currents. At a temperature of (75°C), the durability duration is (192hr.) in the absence of stray currents and (18hr.) in the existence of stray currents. Stray currents, in other words, enhance and boost corrosion, while decreasing durability to static mechanical stress, according to the research which shows [10][11].

That is, in the existence of stray currents and a high temperature of the corrosive environment, the durability of the wires will decrease, as its durability to static tensile stress in the corrosive environment will be less, because of the constant synergy to form pits or holes on the surface of the aluminum wire (pitting corrosion enhanced by stray currents), and this is what speeds up the collapse or accelerates the failure of the wire. This is obvious when comparing the durability duration of two wires, one operating in the corrosive environment at (75 °C) in the existence of stray currents, so that its durability duration is

(18 hr.), and the other, operating in the same corrosive environment at (25 °C) in the absence of stray currents, so that, its durability duration is (408 hr.).

All of this occurs, because tensile stress is connected with corrosion, which creates pitting or fine cavities at the wire surface, which are stress concentration places. This analysis is relevant to the study [3][6][12].

Therefore, it is obvious that the percentage of stimulation increases with the rise of the temperature of the corrosive medium. The highest stimulation ratio was in the existence of stray currents at a temperature of 75°C, followed by the ratio at a temperature of 50°C, and finally the stimulation ratio at a temperature of 25°C that the stimulation increase was 0.17% between corrosion at 50°C and 25°C, the stimulation increase is 1.73% between corrosion at 75°C and 50°C, and the total stimulation increase is 1.9% between corrosion at 75°C and 25°C.

Table 3. The used test conditions and the durability duration of the wires in presence and absence of the external electric current.

Without outer current	
Temp.(°C)	**Durability duration (hr.)**
25	408
50	288
75	192
With outer current	
Temp.(°C)	**Durability duration (hr.)**
25	46
50	32
75	18

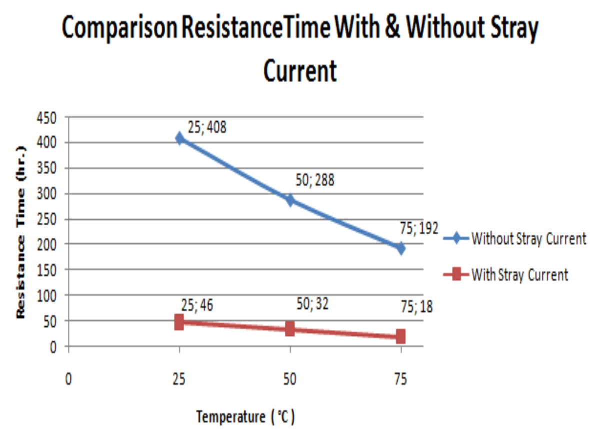

Figure 4. A comparison between the durability duration of aluminum electrical wires in the existence and absence of stray currents under different test conditions.

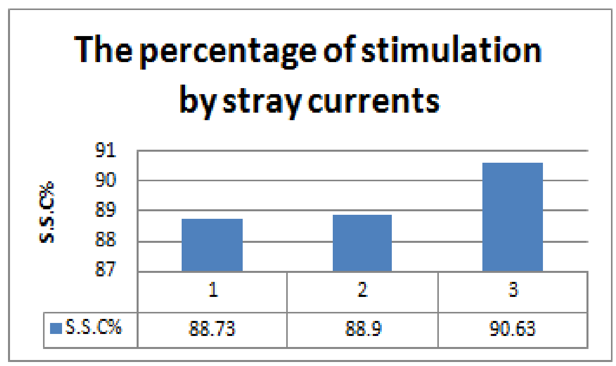

Figure 5. Clarifies the comparison between the three stimulation states for aluminum electrical wires that operate in the three corrosion mediums.

4. Conclusions

The duration period of the aluminum wire to stress corrosion cracking (under static stress) for these research conditions, was influenced by two major factors: first, the temperature of the corrosive environment, which surrounded the wire and was impacted by static mechanical stress, and second, stray currents (external electricity),because both factors served as corrosion stimulators and boosters, when the applied load was set to 1N.

When there was no external electrical current, the durability duration was (408 hr.) at (25°C) and (192 hr.) at (75°C). However, in the presence of stray currents, the aluminum wire has a durability duration of (46 hr.) at (25°C) and (18 hr.) at (75°C).

Since a result, be cautious of the influence of stray currents on mechanical components under tensile load in corrosive environment at various temperatures, the mechanical failure would be hastened. This is consistent with many of the conclusions of previous studies. The stimulation increase was 0.17% between corrosion at 50°C and 25°C, and the stimulation increase is 1.73% between corrosion at 75°C and 50°C, and the total stimulation increase is 1.9% between corrosion at 75°C and 25°C.

Conflict of Interest

The author confirms that the publication of this article causes no conflict of interest.

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