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EQUIPMENT DESIGN FOR THE DEVELOPMENT OF ACCELERATED AGING IN METALLIC MATERIALS

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Abstract: The machines to develop accelerated aging in metallic materials must take care that the test conditions to be carried out are based on representative data of the various corrosion and oxidation situations that the components will face during their performance. Accelerated aging tests can give a hallmark of how the material will behave up to six times faster than it does in real time. As long as these conditions are adequately reproduced in the test. In these teams it is very important to consider the time that the tests last. Due to this, continuous cycles have to be applied, these are generated by means of an adequate design of the control system with the help of a properly programmed microprocessor. The development of the design and validation of the equipment was generated with CAD design software.

Keywords: Accelerated aging, Design, Control, Manufacturing, Numerical simulation.

INTRODUCTION

The equipment for accelerated aging manages its operation by applying test cycles to represent the wear that is going to be carried out, equipment that develops accelerated aging by UV radiation is handled, we also find equipment for humid environments or by handling different degrees of pressure.

In the case of the accelerated aging equipment that is going to be analyzed, we have the application of the variables of temperature, UV radiation and application cycles of a humid environment with a salt mixture.

In the same way, it is very important to consider the time that the tests last. For example, one of the most common tests is in which cycles of up to 2,000 continuous hours have to be applied to be equivalent to 2 years of material exposure. Subsequently, if it is necessary to obtain results for higher values of time, statistical tools or mathematical models that yield adequate results can be used. The accelerated aging equipment handles the following general structure (Figure 1) [2].

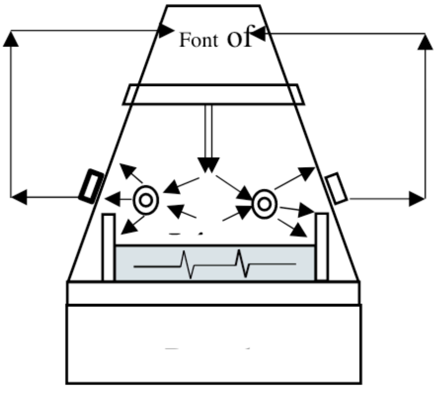

Figure 1.- General structure of UV radiation accelerated aging machines.

The equipment in Figure 1 manages a closed system to control the UV radiation generated to develop accelerated aging, using the following cycle [3]:

1.- Directly select the desired irradiation level.

2.- When UV radiation is applied, the sensors in the equipment will take a census of the light emitted by the lamps. This data is transmitted to the computer controller.

3.- The measurement of the real irradiation value is obtained.

4.- The real value is compared against the established value of the irradiation.

5.- The control instructs the power supply to make the necessary adjustments.

When the components to be analyzed handle long periods of time exposed to humid environments, the moisture attack test can be developed. This attack consists of maintaining a humid environment for 12 hours a day. Condensation is almost always carried out at a temperature of 50 °C, by this condition, the aging effect is accelerated in a better way. Figure 2 shows the cut section of a machine of this type.

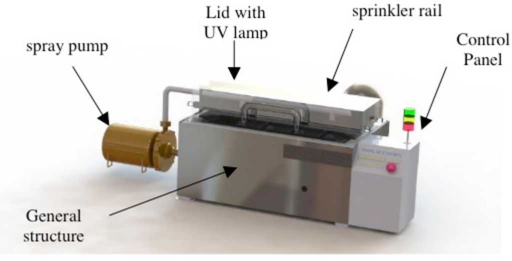

Figure 2.- Accelerated aging machine by humid environment.

DESIGN CONDITIONS

An important condition in this type of test is to seek repeatability, this can be achieved by using water free of impurities and thus avoid stains being generated in the materials to be analyzed. For the development of this team, the following factors are taken into account [4]:

1.- The temperature ranges that must be handled, since the increase in temperature always speeds up the time in which chemical reactions are carried out. In the same way, the materials to be analyzed have different aging speeds, directly related to the temperature being handled. Another very important factor with which the temperature that is handled is related is the relative humidity, since if a low value of relative humidity is handled, corrosion does not take place. The increase in temperature also causes more water to be used, due to the fact that a faster evaporation is generated in the humidity than in the test tubes.

2.- Humidity generates a film on the material being analyzed, although it only occurs when we exceed the relative humidity value. This is above 60%, this effect generates that the film formed on the material is an electrolyte, where it generates the oxidation of the material more quickly, by a cathodic process of Oxygen reduction.

3.- The saturation of the atmosphere, as long as a 99% saturated atmosphere is achieved, the intensity of the corrosion suffered by the material will depend directly on the time in which it is in contact with the electrolyte formed on the surface.

4.- The effect produced by ultraviolet radiation is directly related to the level of corrosion that exists in materials exposed to the elements. The objective is to be able to replicate the effect of the UV rays emitted by the Sun and that handle a short wavelength between 350 to 380 nm. These teams must comply with the corresponding regulations, to comply with its proper operation, the most important are the following.

The ASTM G154 standard indicates the following steps to perform this test [5]:

1.- The radiation exposure test time must be 8 hours. While the temperature at which it must be carried out is 60 °C.

2.- After the condensation cycle, it must be applied for 4 hours. At a temperature of 50 °C in the dark cycle.

The ASTM D4587-0 standard indicates the following steps to be carried out in this test [6]:

1.- The radiation test time is 4 hours. In this interval, the temperature must be in the range of 60 °C, using UV radiation from 300 to 380 nm.

2.- The condensation cycle must be applied for 20 hours, with a temperature of 50 °C in the dark cycle.

OVERALL TEAM DEVELOPMENT

Accelerated aging equipment handles various components, which can be modified as long as their main operation does not change. As well as, the selection of materials must not alter the test results. In this stage of equipment design, CAD computer-aided design was used, which allowed a preliminary visualization of the accelerated aging equipment.

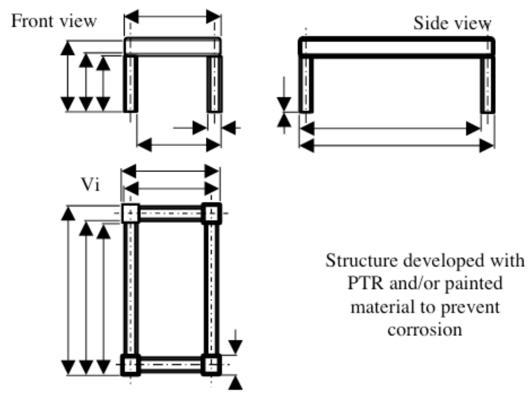

Figure 3.- Preliminary design of the accelerated aging equipment.

In the detailed development of the equipment, all the pieces were designed individually, applying from the materials to the final geometry of each component, in general terms the following parts are found [7 and 8]:

- Equipment structure.- It is the part that provides support to the equipment, since it assembles the tub, specimen holder and all the control of the machine. This piece is assembled by welding, with micro wire. The material from which it is manufactured is a square structural tube, commercially known as PTR, 6 x 6 inches, with a thickness of 3/16 inches, all with the application of paint coating (Figure 4).
- Equipment tub.- It is the space where the camera body is located. Here is the spray equipment, the grids that contain the materials to be analyzed and the drainage system. It also includes the electrical resistance, responsible for

raising the temperature of the water to a range of 40 °C to 90 °C (Figure 5).

- Sprinkler system. - They are placed inside the tub at the top, to apply the solution of water at 50 °C with salt. The objective of this system is to simulate the effect of rain on the materials to be analyzed. The pump in charge of maintaining the adequate pressure for the operation of the sprinklers (Figure 6).

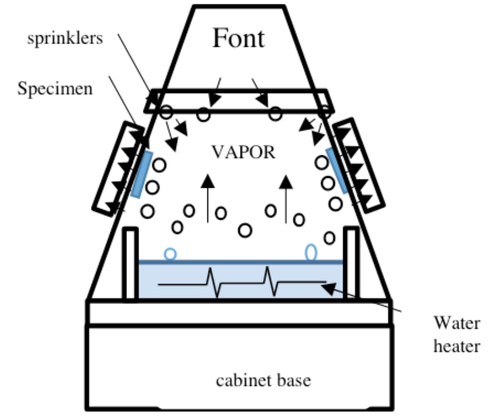

Figure 4.- Team structure.

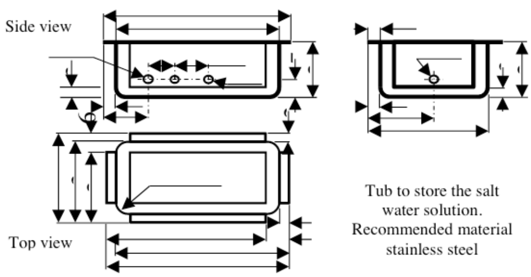

Figure 5.- Equipment tub.

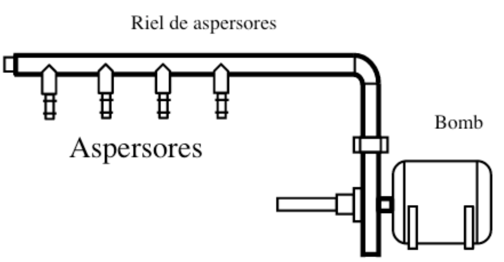

Figure 6.- Sprinkler system.

- The cover of the equipment. - In the cover of the equipment there are slots for ventilation, also the space to install the UV lamp. The application of ultraviolet radiation helps to effectively simulate the wear caused by prolonged exposure to the elements (Figure 7).

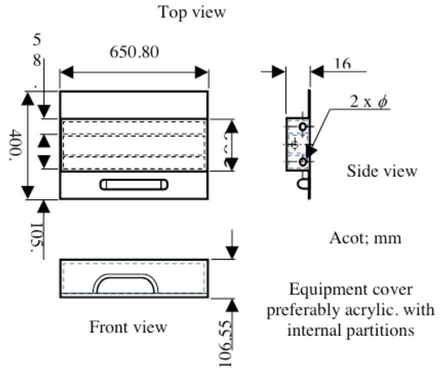

Figure 7.- Equipment cover.

- Specimen holder. - It is the piece that is responsible for containing the material to be studied, it is located in the upper part of the tub. The material from which they are made is stainless steel, to avoid contaminating the material to be analyzed, specifically 316 L, it is suitable for the application sought since it contains 16% Chromium, 2% Molybdenum and 10% Nickel (figure 8).

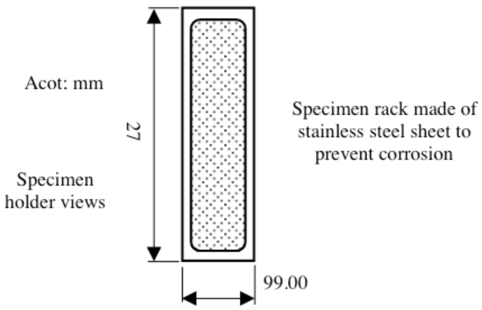

Figure 8.- Specimen holder.

- General assembly of the structure of the equipment to carry out accelerated aging, the equipment will be able to carry out its accelerated aging tests on metallic materials with or without coatings, the studies for metallic materials with zinc coatings can be adequately developed, it is not recommended for studies of materials with organic coatings since they are practically impenetrable. Developing an environment with a high degree of humidity.

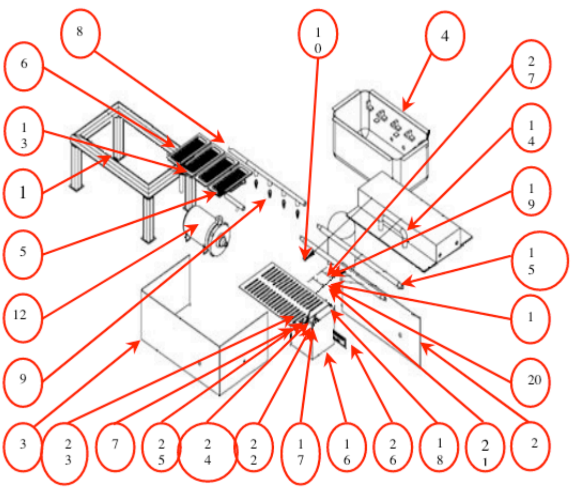

Figure 9.- General structure of the equipment

No. element	section in the component	Description of the material
1	Structure - 1	PTR cold forming ½*½
2	Lid - 1	16 gauge sheet, 1.5mm
4	Tub	T-304 stainless steel
5	Specimen holder	T-304 stainless steel
6	Specimen holder	T-304 stainless steel
7	Rack	T-304 stainless steel
8	sprinkler rail	high density polymer
9	Injector	Pressure 1.5 to 3.0 Kg
10	tub stopper	High density polypropylene
11	Specimen holder at 15°	Polypropylene
12	Water Pump	60W/ 0.8MPa
13	Specimen holder	T-304 stainless steel
14	Top	Acrylic
15	Uv lamp	Rad 200 to 400 mm Long. cool
16	cap hopper	16-gauge sheet, 1.5mm
17	Cap cap	16-gauge sheet, 1.5mm
18	Indicator light base	16-gauge sheet, 1.5mm
19	Indicator lights	high density polymer
20	Specimen holder at 15°	Polypropylene
21	Indicator lights	high density polymer
22	Lid - 3	16-gauge sheet, 1.5mm
23	Rejilla	T-304 stainless steel
24	Rejilla	T-304 stainless steel
25	Rack	T-304 stainless steel
26	Identification plate	high density polymer
27	Specimen holder at 15°	Polypropylene

Table 1.- Relationship of the general structure of the team

Next, the manufacturing and assembly sequence is presented.

MANUFACTURE AND ASSEMBLY OF EQUIPMENT

In the development of the accelerated aging equipment, we find various applications of the different manufacturing processes, since assemblies of various previously manufactured parts are included, where machines and tools of general application are involved, thus leading to the total development of the equipment, by using the following manufacturing sequence for general components:

1.- In the first instance, the cut was developed in the material used for the construction of the equipment structure, ½ in * ½ in square tube.

2.-As a next step, the permanent joints were developed, using the appropriate security measures for the application of this process, this way the welding with micro wire was applied, protecting the welding bead with CO2 gas, which is the most recommended. when working with low carbon content steels, together with the contribution of a rod that constitutes the metal to make the union.

3.-The generation of the tub where the liquid is contained, was built based on a T-304 stainless steel, the applied manufacturing process consisted of the operation of a double team together with the MIG welding process.

4.-The next stage of the process consisted of developing the manufacture of a test tube holder, using a ½-inch square tube frame, together with the stainless steel grid. This will prevent the test tubes from being contaminated with residues emitted by the test tube holder.

5.- The development of the sprinkler system is coupled within the structure, the sprinkler system is located on the specimen holders, to maximize the percentage of moisture that the material to be analyzed receives.

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CONTROL SYSTEM

After the development of the structure with the necessary actuators, the control device is generated, which is the one that is in charge of the control in the sequence of operation of the equipment.

To control the process variables, an adequate control system must be developed, the system model is as follows:

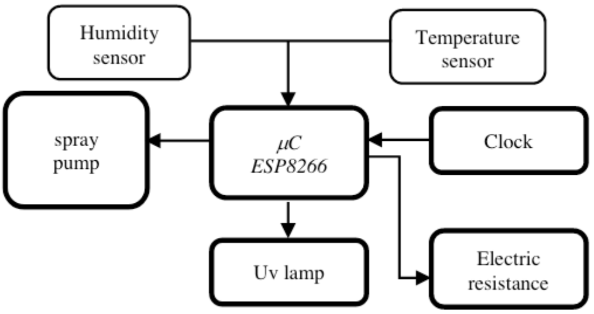

Figure 10.- Model of the control system.

Section titles must be justified to the

The ESP8266 microcontroller consists of a 3.3 VDC powered chip with 64 kB memory and 96 kB data. This microcontroller has the option to link to a Wi-Fi network, in order to use the principles of industry 4.0. With this device the data of the temperature sensor, the humidity sensor and the clock will be received, with these data we can control the UV lamp, the electrical resistance and the electrovalve.

The control device card was designed for the temperature sensors, the UV lamp and the drive pump of the sprinkler system.

The top and bottom of the control card are shown in the figure. [14]

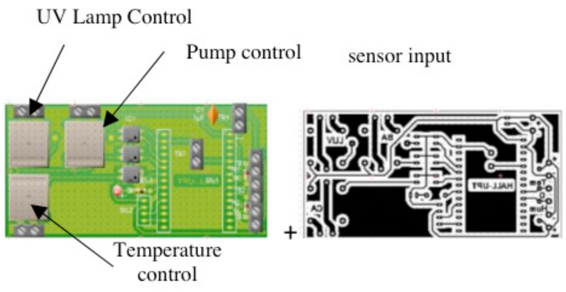

Figure 11.- Top and bottom view control card

SEQUENCE OF OPERATION

Accelerated aging machines need to establish adequate sequences to carry out their operation effectively, according to the aforementioned, the sequence that will be developed per week is as follows, the days of the week will be taken as reference [13]:

1.-Monday and Friday. - The following sequence will be developed during a period of 12 hours.

Application every 15 min of the spray of water at 1% NaCl, for 2 min. A relative humidity of 95 to 99% must be guaranteed.

The initial temperature of the study must be 35°C, with increments of 2° until reaching 45°C and maintain that temperature until the end of the 12-hour cycle.

The application of UV light will be maintained for the duration of the test for 12 hours.

2.-Tuesday, Wednesday and Thursday.- The following sequence will be developed during a period of 12 hours.

Application every 15 min of salt-free water spray for 2 min. A relative humidity of 95 to 99% must be guaranteed.

The initial temperature of the study must be 35°C, with increments of 2° until reaching 45°C and maintain that temperature until the end of the 12-hour cycle.

The application of UV light will be maintained during the 12-hour duration of the test.

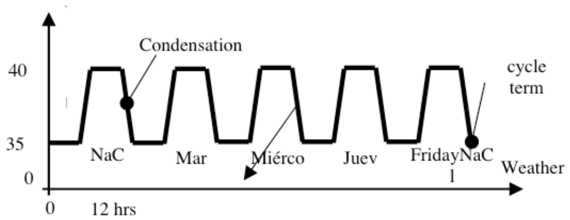

Figure 12.- Accelerated aging cycle

NUMERICAL SIMULATION OF THE SPRINKLER SYSTEM

The analysis of incompressible fluids has been the subject of study due to the complexity of this analysis, the movement of fluids allows calculating the speed of the particles, the pressure that is generated and the direction of displacement that it will have.

The development is carried out using the qualitative flow analysis tool of the mechanical design software, Solidworks. which allows us to obtain results on pressure fluctuations, flow rate and other parameters attributed to hydrodynamics.

The study will be carried out applying an inlet pressure of 0.8 Mpa, by means of a 60 W pump, which yields a volumetric flow rate of 5 L/min, finally the temperature applied in the study will be 313.15 °K.

The maximum speed that was obtained for the particles at the outlet of the sprinkler rail is 3.27 m/s, with this value it can be guaranteed that the humidity will be found throughout the body of the specimens to be analyzed, the condition of the turbulent flow In both cases, it is beneficial to consider the increase in relative humidity inside the chamber [13].

Figure 13.- Flow simulation

CONCLUSION

The development of equipment for the generation of accelerated aging seeks, through a corrosive atmosphere, to verify the behavior of metallic and non-metallic materials during periods of time that generate the effect of accelerating aging through the oxidation process. The main standard used for the construction of this equipment is ASTM B117 (1997) "Salt spray fog test". In the same way, the general characteristics of the equipment that are currently available in the market for the generation of this product were taken into account.

De forma general el funcionamiento del equipo cosiste en exponer la probeta que se va a analizar a condiciones controlled temperature, humidity and exposure to UV light. The development of the test must be duly monitored so that it can be properly documented, during the entire period in which they are under the exposure of the study, for this a control system was designed capable of withstanding during 5 continuous days of work, the application of the previously established accelerated aging cycles, which consist of the application of saline mist with intervals of UV lamp application.

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REFERENCES

[1] J. Van der Geer, J. A. J. Hanraads, R. A. Lupton, Journal of Science Communication **163** (2000) 51.

[2] Appleman, B. R. y Cambell, P. G., Salt spray testing for short term evaluation of coatings; Part 1, Reactions of coating in salt spray, Journal of Coatings Technology, Vol. 54, No. 3, pp 17-25, 1982.

[3] Sherwood, A. F., The protection of steelworks against atmospheric pollution, Paint Research Association, Technical Report 8, pp 87, 1987.

[4] Suarez, C.X., Villar, L.R., Corvo, P.F., Marrero, R., Resistencia al clima tropical de aceros galvanizados con y sin recubrimiento, Ingeniería Investigación y Tecnología, Vol. 15, No.1, pp 29-40, 2014.

[5] Chico, B., De la Fuente, D., Simancas, J. y Morcillo, M., Corrosión atmosférica de metales, efecto de parámetros meteorológicos y de contaminación, Revista de Química Teórica y Aplicada, Vol. 62, No. 519, pp 479-486, 2005.

[6] ASTM G154-12a., Standard Practice For Operating Fluorescent Ultraviolet (UV) Lamp Apparatus For Exposure of Nonmetallic Materials.

[7] ASTM D4587-11., Standard Practice for Fluorescent UV- Condensation Exposures of Paint and Related Coatings.

[8] Skerry, B. S., Alavi, A. y Lindgren, K. I., Environmental and electrochemical test methods for the evaluation of protective organic coatings, Journal of Coatings Technology, Vol. 60, No. 765, pp 97-106, 1988.

[9] Barton, K., Protection Against Atmospheric Corrosion; Theories and Methods, Ed. John Wiley and Sons, pp 23-25, 1976.

[10] ISO 9226, Corrosion of Metals and Allows; Corrosivity of Atmospheres, Methods of Determination of Corrosion Rate PF Standard Specimens for the Evaluation of Corrosivity, Ed. ISO, Geneve, 1991.

[11] ASTM B117-11, Standard Practice for Operating Salt Spray (Fog) Aparauts, Ed. ASTM, 1991.

[12] Hosking, N. C., Ström, M. A., Shipway, P. H. y Rudd, C. D., Corrosion resistance of Zinc-Magnesium coated steel, Corrosion Science, Vol. 49, No. 9, pp 3669-3695, 2007.

[13] Nichols, M., Boisseau, J., Pattison, L., Campbell, D., Quill, J., Zhang, J., Smith, D., Henderson, K., Seebergh, J., Berry, D., Misovsky, T. y Peters, C., An improved accelerate weathering protocol to anticipate Florida exposure behavior of coatings, Journal of Coating Technology and Research, Vol. 10, pp 153-173, 2013.

[14] Taylor, W. R., Roland, E., Ploeg, H., Hertig, D., Klabunde, R., Warner, M. D., Hobatho, M. C., Rakotomanama, L. y Clift, S. E., Determination of orthotropic bone elastic constant using FEA and modal analysis, Journal of Biomechanics, Vol. 35, No. 6, pp 767-773, 2002.

[15] Chen, X., Rao, C. P. y Wan, D. C., Numerical simulation of water entry for two-dimensional wedge by MPS, Chinese Journal of Computational Mechanics, Vol. 34, pp 356-362, 2011.

[16] Goto, H., Advanced particle methods for accurate and stable computation of fluids flows, Frontiers of Discontinuous Numerical Methods and Practical Simulations in Engineering and Disasters Prevention, Ed. CRC Press, pp 113-122, 2013.

[17] Kirankumar, V., Kataraki, K. y Sheshgiri, M. S., A performance study of moving particle semi-implicit method for incompressible fluid flow on GPU, International Journal of Distributed Systems and Technologies, Vol, 11, No. 1, pp 83-94, 2020.

[18] Zhu, X. S., Cheng, L., Lu, L. y Teng, B., Implementation of the moving particle semi-implicit method on GPU, Science China Physics, Mechanics and Astronomy, Vol, 54, pp 523-532, 2011.