STUDY OF THE BEHAVIOR THE FATIGUE OF METALS INSIDE AND OUT OF THE WATER IN THE PRESENCE OF THE HYDROSTATIC PRESSURE

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Abstract. *The objective was to study the behavior of resistance fatigue of material ASTM A-36 rehearsed in three ambients: refrigerated with water, inside of one it laminates of water and inside of water in the presence of hydrostatic pressure of 5 atm, through rotating bending tests of fatigue. Soon afterwards they were made analyses and comparisons of results of tested material. For the study developed a mechanism of test fatigue for rotating bending to be used inside and out of hyperbaric chamber for the simulation of hydrostatic pressure. This study is valid, because any confirmation of resistance doesn't exist the "underwater" fatigue of virgin materials, in other words, all the tests of fatigue that were or they are being accomplished in materials are being done to the air. Soon afterwards they were determined curves S-N for each atmosphere. The methodology used for verification of resistance to the fatigue went using regression model for data originating from of accelerated life tests. For the study of involved phenomena it was made hardness analyses, microhardeness.*

Keywords*: Fatigue, rotating bending, curves S-N-P, fracture.*

1. INTRODUCTION

Due to the expansion of hydroelectric plants and petroliferous, studies related to useful life of metallic components are in constant development in universities and industries to perfect the existing technologies [Maddox, 1998]. That measured search to guarantee a larger durability of the structures, to increase the competitiveness of companies and to prevent accidents that harm the environment and economy.

The platforms modern petrolíferous are projected to support exhibitions to the efforts provoked by storms, hurricanes and great amounts of waves. Those efforts apply a shipment in structure favoring the failure for fatigue of some component of same one.

Are considered that estimate of useful life of structures submitted to that phenomenon it is of great importance in project of a work or equipment to guarantee your stability [Taier, 2002]. For this, the necessity of a study fore subject analysis structures exists fatigue.

All the solicitations that vary in intensity and/or direction provoke variations of tensions in structure and they can cause failure for fatigue. The alive and ambient loads are important in this association, because they possess the biggest parcel of load in structure [Kiepper, 2004]. It must consider the action of hydrostatic pressure in set with too much efforts for failure under water fatigue.

In the last decades, the progress of the technology under water turned the innovative projects in challenge for the development of coastal and oceanic structures to assist the most diverse economic necessities. One parcels out significant of these structures, used mainly for industries of gas and oil, is immersed in aquatic environments, subject to hydrodynamic efforts, as presented in Figure 1.

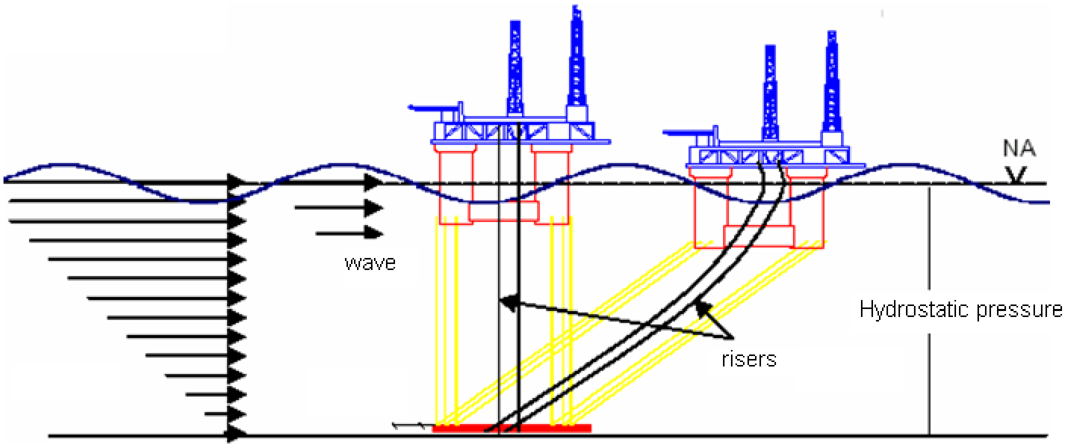

Figure 1. Interaction fluid-structure

In general, a structure is projected to carry out your function with an appropriate safety and economy. The collapse of a subject structure the loads can occur of two different forms [Taier, 2002]:

- Occurrence of a high level of tensions that exceeds capacity of resistance of material, provoking failure, for example, rupture or instability of a structural component;
- The structural collapse caused by accumulated damage produced by repetitive action of variable loads, even for lower levels of applied tensions, generating a process of fatigue.

2. FATIGUE

The term fatigue can be defined as a process for which gradual and located changes of irreversible nature occur in material subject to tensions or floating deformations. These efforts can result in cracks or the complete failure of materials. [ASTM E-1823-96].

The mechanism of formation of imperfection for fatigue in metals initiates with formation of slipping bands [Sunder, 2005]. These are caused by movement of discords in reticulate crystalline of metal, leading the formation of intrusions and extrusion. As consequence, they are formed local for nucleation of cracks, for accumulating great located plastic deformation. These cracks propagate in each cycle of tension until instability.

For study of degradation for fatigue it is necessary to develop assays that present typical cycles for each situation. The operating tensions in component must be known that will be analyzed: to regulate, random and/or aleatory.

2.1 Method S-N (it Fatigues of high cycle)

Method S-N is study of fatigue by means of diagrams S-N, located with variation of tension versus number of cycles. It is denominated of high cycle, due to great amount of cycles for occurrence of flaw for fatigue. The assays for determination of diagram S-N are made in samples or components of proper structure, guide for norm [ASTM E-466, 96], with shipment total reverse, as presented in Figure 2..

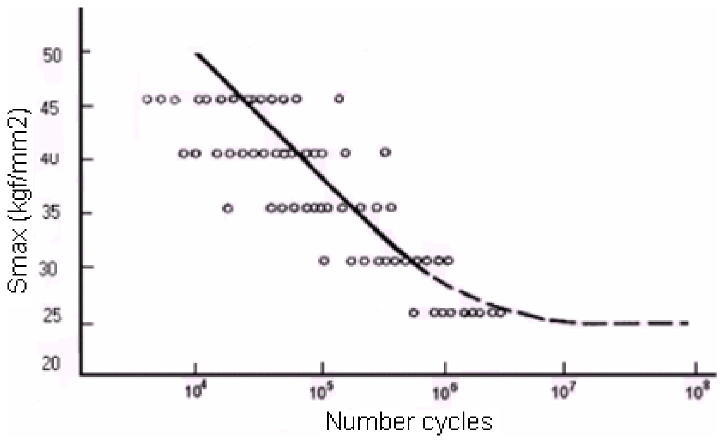

Figure 2. Curve for constant tension

Some materials under constant shipment conditions exhibits, in its diagrams S-N, amplitude of tension below of which same is not subject to failure for fatigue, independent of number of cycles. This calls limit of fatigue or limit of endurance, If, and varies enters 35 50% of limit of rupture of material, *Su*. Some metals, as aluminum and its leagues, don't present this defined limit [Suresh, 1998].

Although its great use in engineering curves S-N present some limitations [Son, 2002]. That method is not capable to separate initiation stages and of propagation of crack, bringing difficulties in evaluation of behavior of mechanical elements with accented incisions and structures with failures.

2.2 Determination of resistance limit to the fatigue (S_e)

The values obtained at laboratory for limit of fatigue, are used as base for sizing of some piece. However, difficultly value of breaking of material in practice, when submitted the some repetitive effort, it is same to the obtained at laboratory. Innumerable variable exist that influence in practical values of rupture for fatigue, from exposed environment and format of piece.

For work regression model was used for data originating from of accelerated life tests and adjusts for determination of the resistance limit to the fatigue.

The test of accelerated life means to accelerate appearance of cracks in tests with products. The obtained experimental results are led in stressful conditions and used to esteem conditions in project. This can be applied in studies of fatigue occurrence [Freitas and Colosimo, 1997].

2.3 Description of regression model

That model requests that some are made hypotheses. One of them is that the variability is same for each tension level, however that not always it is true. However, a lot of times when it works in another scale, for example, in logarithmic, that supposition become approximately valid [Mansur, 2003].

The log-normal distribution is one that better describes life times whose failure mechanisms involve chemical interaction, found a process of corrosion and degradation of contacts. It is also indicated for failure mechanisms for fatigue in materials [Freitas and Colosimo, 1997].

The mathematical equation that better describes the relation between the tension (*S*) and the number of cycles to failure (N) is of linear regression (regression curves), given by Equation 2.10 [Maluf, 2002]:

$$\log(N) = b_0 - b_1 \log(S) \tag{1}$$

$$Y_i = \beta_0 + \beta_1 x_i \tag{2}$$

Where, Y_i is logarithmic N and x_i is logarithmic tension.

2.4 Adjust of regression model

The adjustment for this model considers distribution of values in log-normal. After that, function of confiability of log-normal distribution and made inverse calculation is used to establish resistence limit to fatigue for steel.

The function of reliability of the log-normal is given for: $R(T)=P(T \geq t)$, being the probability of time to failure of metal, either bigger than a definitive time t [Freitas and Colosimo, 1997] and is given by Equation 3.

$$x_0 = \frac{1}{\beta_1}\left[\Phi^{-1}\Gamma + \ln(t) - \beta_0\right] \tag{3}$$

Where, Φ^{-1} it is value of z (normal standard) corresponding to percentil of interest. Parameters: $\hat{\beta}_0$, $\hat{\beta}_1$, e $\hat{\Gamma}$ they are esteem by model, t it is time of interest life and xo is tension level.

The calculation for resistence limit to fatigue is made using value x_0. This is probability of that samples comes to failure, after a number of cycles This value is used in verification of estimates obtained by method direct calculation using log-normal distribution (Method of regression models for deriving data of tests of accelerated life).

2.5 Verification of model

One of most significant tools for verification of adaptation of a regression model is analysis of residues. With that analysis, it is possible to discover suppositions on residues of model they are satisfactory, that is, to verify suppositions of variance equality, of normality and of independence they are accomplished. Those validities can be verified by means of graphs [MARTINEZ, 2002].

3. METHODOLOGY

For work, the steel chosen for survey of curves S-N was ASTM A-36 [ASTM 36M-00a], acquired in market in circular bars of diameter of 1/2 ", where if it removed samples. This type of steel very is used in under water structures, for if treating with a material that is classified as a steel carbon of average resistance mechanics.

The samples, had been assayed in fatigue machine bending rotating to verify the number of cycles necessary to occur its rupture. The assay occurred with sample rotating to one determined speed and with load application to provoke fatigue, [ASTM, E 466-96].

The applied tension is directly related with employed weight. The disposable weights in equipment are: 44,72; 38,38; 19,43; 18,67; 9,43; 5,29; 3,76; 2,36; 0,79; 0,49 N. For determined tension values sum was used of some of described weights.

For refrigerated assays, after it samples to be fixed in machine without load application, in other words, Fcp=0. The necessary weight is applied to have the wanted tension. After that, is motor worked.

For assays sheet of water in hydrostatic pressure with 5 atm (done inside of hyperbaric tank), after to position machine and to prepare it was necessary weights, the recipient is completed with water. In case of tank, it pressurizes to reach the wanted pressure. Soon after, it works motor leading off test of fatigue. To failure sample, machine turns off automatically.

The chosen Experimental Plan for accomplishment of rehearsals was Plan of Commitment [Freitas and Colosimo, 1997; Mansur, 2003; Júnior, 2006]. In this plan three levels of tension are used: high, intermediate and low.

The high level is chosen by practical considerations. Intermediate and low levels are chosen to minimize the assintotic variance of estimator 100P %, relative to percentile of distribution of time of useful life of sample. The commitment of that exists ratio of allocation (ratio of samples that the tests in each level of tension will have to be submitted) either always in 4:2:1, for levels low, intermediate and high, respectively.

In present work, five levels of tensions, being two for linear interpolation had been used, with exception of cooled assay that had been seven levels. For two environments same tensions with purpose had been used to compare results.

4. RESULTS AND DISCUSSION

For the rising of curves S-N, 5 levels of alternate tension were used for assays in s water pressurized to 5 atm. For refrigerated atmosphere 7 tension levels were used, because didn’t know which was best tension, as presented in Figures 3 and 4.

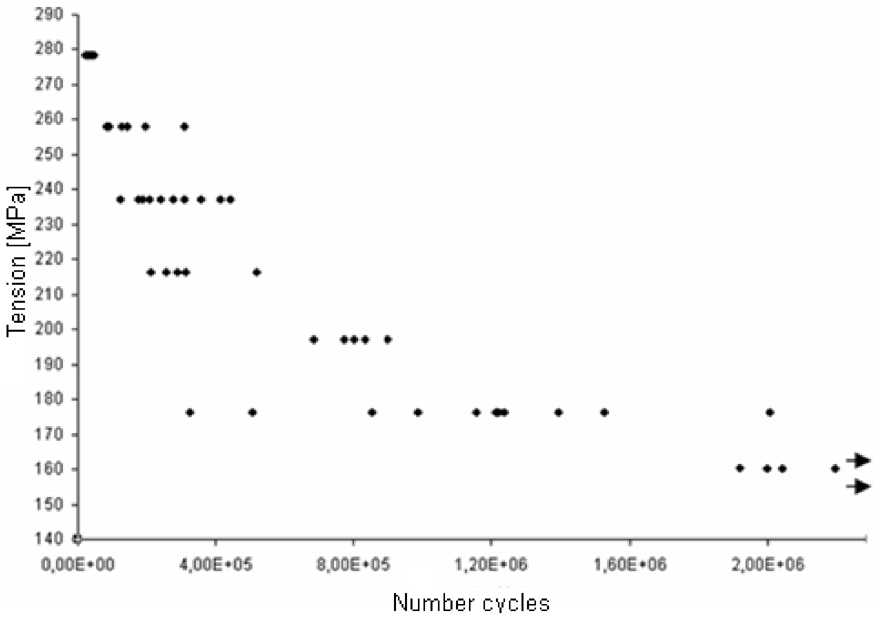

Figure 3. Refrigerated atmosphere samples

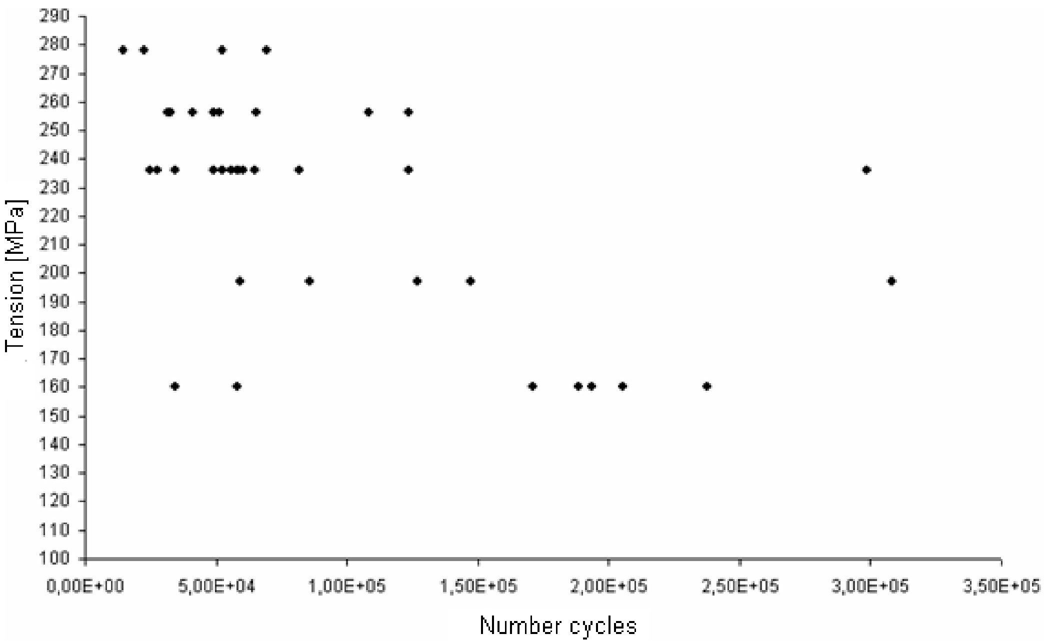

Figure 4. Pressure in water 5 atm atmosphere samples

4.1 Adjustment of model of regression for samples refrigerated and pressure in water 5 atm atmosphere

The estimate of parameters of that model and verification of same ones were made using the softwares MINITAB, version 13 and Microsoft Excel, 2000. In Figures 5 and 6, values of standardized residues e are presented, after that values of variables.

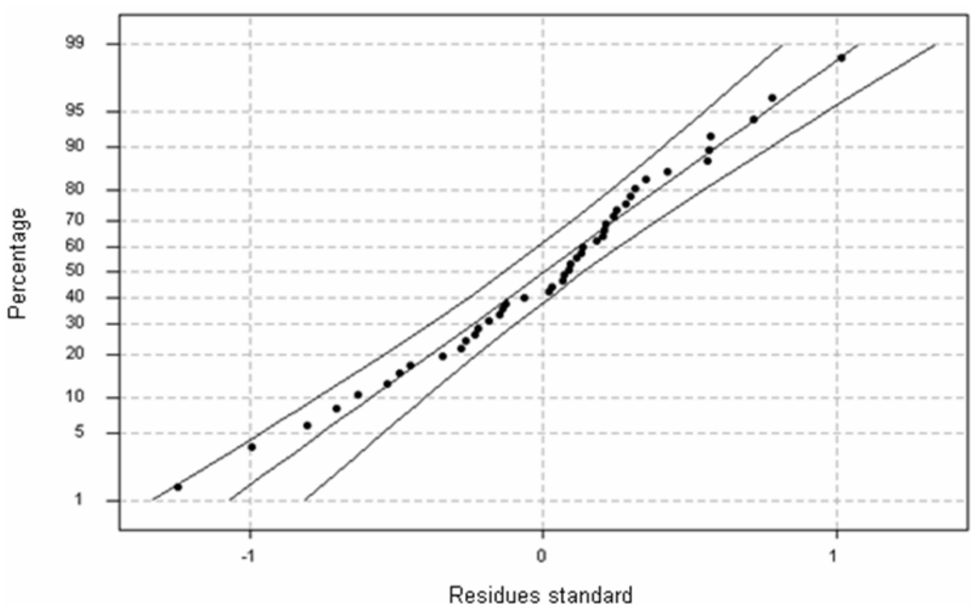

Figure 5. Residues standard refrigerated

The results obtained by graph they were:

- Intercept = 19,02899,
- Coefficient of variable predictor = -0,02874,
- Parameter of scale of Log-normal distribution = 0,43843.

The model obtained above according to result it is following:

$$Y = \ln(T) = 19{,}02899 - 0{,}02874x + 0{,}43843\varepsilon \quad (4)$$

For adjustment of model of regression for pressure in water 5 atm,

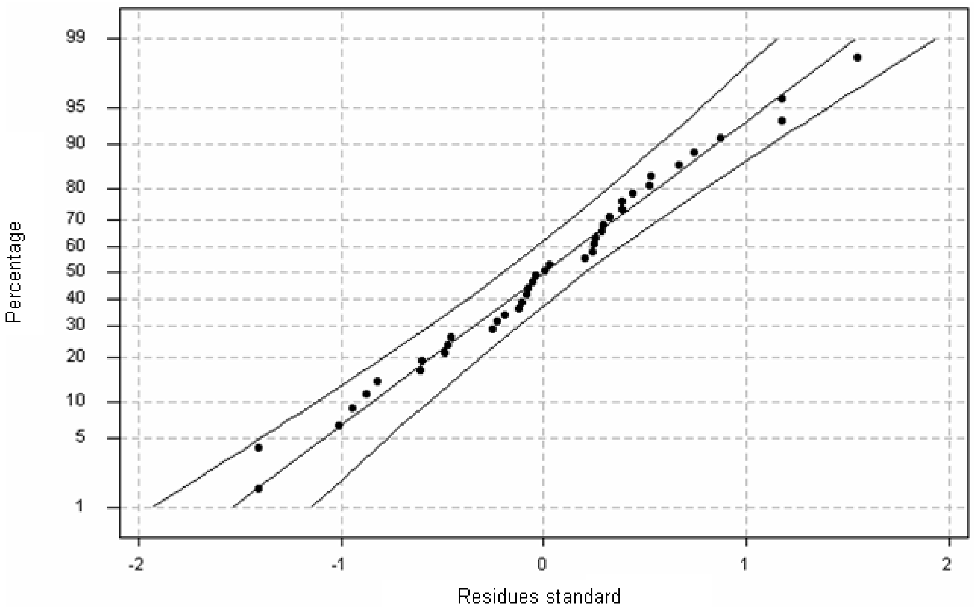

Figure 6. Residues standard for pressure in water 5 atm

The obtained results were:

- Intercept = 13,51672,
- Coefficient of variable preditora = -0,01042,
- Parameter of scale of Log-normal distribution = 0,73778.

The model obtained above according to result it is following:

$$Y = \ln(T) = 13{,}51672 - 0{,}01042x + 0{,}73778\varepsilon \quad (5)$$

The statistical analysis of results indicates that value of residues (adjusted values - observed values), placed in a graph of normal distribution, approaches of a straight line and they are inside of strip of 95% of confiance and without any configuration that demonstrates unsatisfactory behavior. The model in question is adjusted for study.

4.3 calculation of resistance limit to fatigue using regression model

With values gotten in adjustments of curves S-N for environments is applied for refrigerated, adopted 2.000.000 cycles as probability of failure of 50% for samples.

$$x_0 = \frac{1}{-0{,}02874}\left[0 \times 0{,}43843 + \ln\left(2 \times 10^6\right) - 19{,}02899\right] = 157MPa \quad (6)$$

For atmosphere pressurized with water to 5 atm, item 4.6.2.3, applies, but due to obtained values of curve S-N, adopted 500.000 cycles as probability of failure of 50% for samples.

$$x_0 = \frac{1}{-0{,}01042}\left[0 \times 0{,}73778 + \ln(500.000) - 13{,}51672\right] = 38MPa \quad (7)$$

When being based in the works of Sterverding (1964) and Hudson (1972) it verifies that resistance limit to fatigue is influenced by applied atmospheric pressure. That can be associated occurs in assay pressurized to 5 atm with water.

In relation to obtained values, Hahin (1994) made a research and tells that steel SAE A-36 has an Endurance limit to Fatigue to 23 air of Ksi (158,58 MPa) using bending rotating assay. The value found in work is in accordance with values literature, as presented in Figures 7.

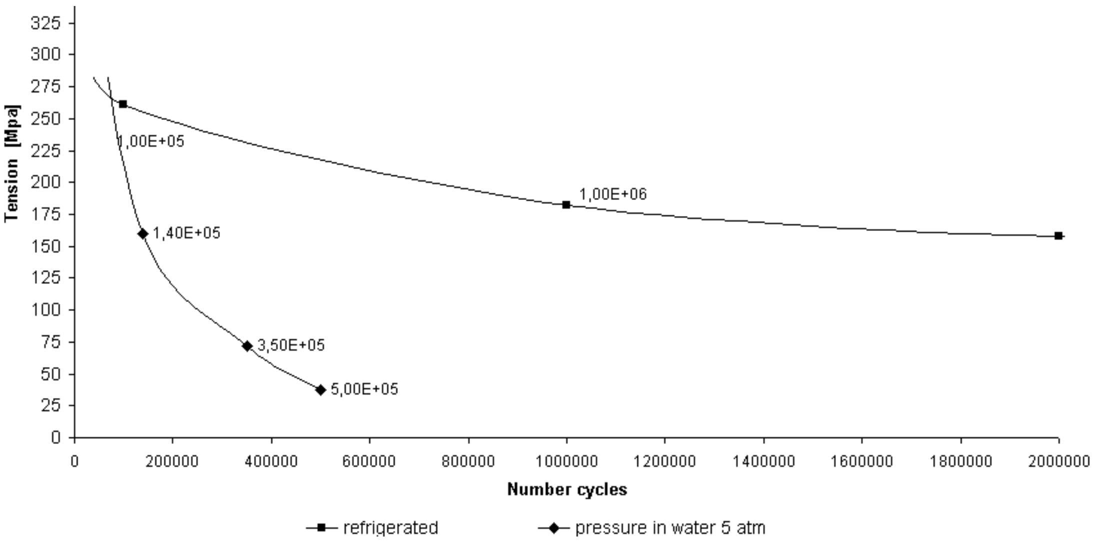

Figure 7. Resistance limits fatigue for two atmospheres with probability of failure of 50%.

5. CONCLUSION

For assays pressurized with water 5 atm, had to number of obtained low cycles, considered a probability of failure of 500.000 cycles.

In the work they were lifted up two hypotheses to explain those differences obtained in assays pressurized to 5 atm:

- Some of them associated to dissolved air, or air bubbles, in water that could contribute to decrease of resistance to fatigue. That was noticed at end of test, because area of fracture presented oxidated, with pits reducing number of cycles for the crack nucleation. It is also verified that the effect of the tension has an effect in the life to the fatigue of the material, [CASTRO, 2007];
- The other, it deals with cavitation phenomenon that occurs for movement and turbulence of fluids in a metallic surface. This happens due to collapse of air bubbles in surface of metal, pressure and speed of test. Salient that the cavitation displays material to corrosive consuming and assists in formation of pits [CASTRO, 2007].

It evidences that pressure has an important paper, therefore in assay in pressurized water 5 atm occurred to precocious ruptures.

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