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# DISPERSION OF FATIGUE TEST RESULTS ON SMALL DIMENSION COMPONENTS

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***Abstract.*** *Mechanical components subjected to cyclic stresses can break with lower loadings than the necessary to rupture in an almost static loading. Besides the loading, the geometry and the surface finish, as well as other factors that influence the properties of the boundary layer, determine the number of cycles and the loading that can be applied to the component. In order to avoid possible failures caused by fatigue, components manufactured in various materials should be subjected to fatigue tests. The tests should mimic the loads representing the loadings in which the components will be used and allow the designer to ensure that they have sufficient resistance to act in their future activities and be able to withstand the loads that will be assigned. These tests are time consuming and its results are quite dispersed, so, for this reason, it is necessary to perform many tests in order to get a reliable result. To reduce the evaluation time of fatigue behaviour of small components, an equipment for rotating bending test with multiple parallel axes, controlled by a single servo-controlled motor was designed and built. To certify the adequate function of the equipment specimens made of AISI 1020, cold drawn steel bars with 8mm in diameter, with a central strangulation were machined with the same machining conditions on a CNC lathe, thus representing the element under evaluation. For the analysis of failures, tests were conducted under different loads, applied in the free extremity at a preset distance from the strangulation, where the test load by a weight is applied. The results show a typical behaviour that has been observed by Wöhler, reducing the number of cycles with increasing load and presenting infinite life for loads below the critical stress. However, it was observed that the dispersion of the results was quite large, which requires a refinement of the test to ensure reliable information to the designer. No dependence of the individual axis of the equipment was observed.*

***Keywords:*** *Fatigue, failure, dispersion, fatigue test.*

## 1. INTRODUCTION

Any material when subjected to cyclic stresses is susceptible to failure, so it is necessary to make verifications and validations about the resistance that the material has, in order to avoid damages possibly caused by the failure or breakage of materials. Fatigue tests allow to investigate and predict the behavior of materials, and identify which places are susceptible to failure, which is very important for the medical and dental fields, where small mistakes can bring irreparable damage. Thus, it is possible to realize that the importance of fatigue tests is growing with the demand for implants.

The fatigue test is used to determine the fatigue life, locate faults and define the behavior of materials when exposed to changes in load or disturbances. Generally the test is repeated with different load cycles, but with identical samples. It is important to carry out the tests less complicated and time-consuming way in relation to the component will be subjected throughout his life, as in the aircraft industry, for example, where many years of service are reduced to a few months for the tests to be performed, and only one or two prototypes of a new aircraft are used for this. However, in these cases, you must keep a known relation between the experimental results and their performance in service, and take into account also the need to test the ability to accurately reveal the structure and the fatigue resistance. Shorten the test has the advantage of eliminating the rest periods and the very small range of loads without affecting the results. Entails, however, the drawback of complicating the analysis required for the relationship between the results and performance, in addition to making it difficult to relate the lives of the test and the expected service, being necessary to use different assumptions to correlate (Rosa, 2002; Instron).

Fatigue occurs by stresses, which originate by cyclic plastic deformation at critical sites and that, in turn, damage the material, yielding a fatigue crack growing enough to result in a final break (Callister, 2005; Rosa, 2002).

Fatigue is a permanent structural change of a material, namely, progressive failure or breakage of the material. It is originated when subjected to a lower load at that maximum that the material is able to withstand and it happens because of repeated cyclical solicitations. The cracks formed in the region of maximums of stress on the component cause the slow rupture of the material, this being the reason for the gradual reduction of the carrying capacity of the component. The fatigue strength is defined as the number of cycles that a component resists when subjected to a given load. The infinite life is defined by the load which does not cause the nucleation of cracks and therefore does not lead to component failure (Callister, 2005; Rosa, 2002; Instron).

The material fatigue is the most common cause of all the causes of failure of mechanical components, which means gradual decrease in load capacity thereof by the slow breakdown of the material. This occurs as a result of the advancement of the cracks formed therein, and this growth occurs for each stress variation (Collins, 1993).

A system that no longer performs the necessary functions for which it was designed can be said as a failed system and may or may not be associated with rupture or component fracture. For causing economic losses, endanger human lives and interfere with the availability of products and services, the flaws in materials are almost always undesirable. The failure occurrence ratio is given the choice and improper processing of materials, and the inappropriate design of the component or its misuse. And while the causes of these failures are known, it is hardly possible to ensure that they do not occur, so it is important that the engineer be responsible for planning and anticipation of possible failures, because if it happens, one can evaluate the causes and take appropriate preventive measures in order to prevent future incidents (Callister, 2005; Rosa, 2002).

The process of fatigue failure shows a remarkable dispersion in the results, and this can lead to significant uncertainties of fatigue life. This dispersion occurs as a consequence of fatigue sensitivity and of the tests parameters that cannot be controlled accurately. Included in these are: manufacturing parameters of the specimen, surface integrity, metallurgical variables, residual stresses and test frequency (Callister, 2005; Rosa, 2002; Schijve, 2009).

The dispersion of data, according to Rosa (2002), is a feature that should be considered in any problem that is related to fatigue, especially when lives are greater than $10^4$ cycles. This occurs as a result of nucleation process, which in turn, is strongly influenced by metallurgical inhomogeneities, which are dispersed throughout the volume of the material, randomly.

According to Wöhler *apud* Callister (2005), the greater the magnitude of the stress, lesser the number of cycles that the material is able to withstand before fracturing. The S-N curve tends to become horizontal at higher values of N, therefore below the stress threshold level, fatigue limit, the fatigue failure does not occur. The fatigue limit is the highest floating stress value that will not cause failure to an infinite number of cycles.

Fatigue has been known for over 150 years, mainly for metals that have a lower resistance under conditions of cyclic loading compared to static charge. For over a century the common engineering practice has been to characterize the fatigue resistance against cyclic loading materials through Wöhler curves, also called S-N curves or σ-N. This curve is used to obtain the fatigue life for each load level. The typical S-N curve, which can predict the life of a component when subjected to a given level of alternate stress, it can be observed in Fig. 1 (Lee *et al.*, 2005; Schon *apud* Pinagé, 2012).

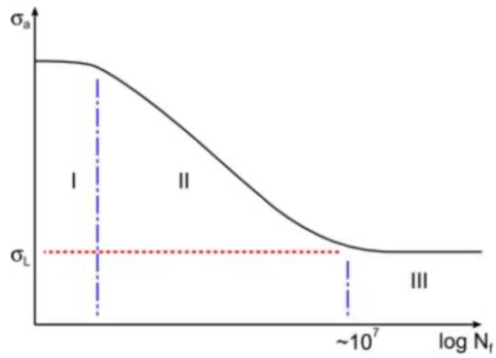


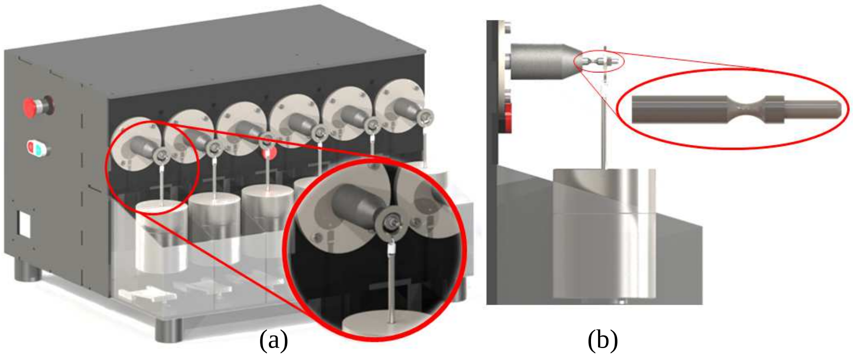

Figure 1. Typical S-N curve.

This graph represents the stress amplitude (σ or S: vertical axis) against the logarithm of the number of cycles until the fatigue failure (N: horizontal axis). Indicated in the graph, you can see three distinct and well-defined regions. In the region I the stress is close to the limits of endurance of the material. The region III is called the infinite life of the region. And in region II it was observed that the stress tends to a limiting value, called the fatigue limit, where, regardless of the number of cycles as long as the stress remains below this value, failure does not occur (Callister, 2005; Lee *et al*., 2005; Pinagé, 2012).

## 2. MATERIALS AND METHODS

In order to evaluate the fatigue behavior of small components, a testing machine for rotating bending fatigue tests was designed and build. This machine presents six parallel axes centrally driven by a servo-controlled motor (Fig. 2a). At the free end of each of these axes is fixed a specimen. Each specimen is provided with a bearing on which the load is applied, and this load is performed by calibrated masses.

For the validation of the above-referenced equipment, specimens were manufactured in cold drawn AISI 1020, as shown in Fig. 2b. The rotating bending tests were performed at 16Hz, at room temperature of 22°C, controlled by an air conditioner. Tests are performed on the six axes rotating simultaneously with the application of the same or distinct loads in different specimens.



(a) (b)

Figure 2. (a) Rotating bending fatigue testing equipment; (b) specimen geometry

To perform the tests loads ranging from 5kg to 10kg were applied. With these weights a maximum tensile stresses of ~1415MPa was obtained, leading to premature rupture of the specimens until tensile stresses of ~705MPa, which led to infinite life as a result of the tests. Thus, it was possible to predict the region which separates the regions of high and low fatigue cycles and the region of infinite life of a classical Wöhler curve.

## 3. RESULTS AND DISCUSSION

For the different axis and variable loads, graphs were generated, obtaining in this way the individual S-N curves (Wöhler) for each of them. As expected, meeting the specifications of S-N curves studied, the load had great influence on the test results. Decreasing the load, the number of cycles that the specimens resisted, increased, until, at a limit tensile stress, resisted 10 million cycles and at this stress it was considered that they had infinite life.

The first tests, named 1, were performed at the axis 1, and the results are shown in the graph of Fig. 3. For high tensile stresses the number of cycles decreases rapidly with the diminution of the stress. Thereafter the curve begins to flatten at a tensile stress slightly below 800MPa, in other words at the transition between 5.5 and 6.0 kg of applied load on the specimen. These results do not enable a conclusion on the dispersion of the data for high stresses, since the tests on each axis, with the same load, were few in number.

One of the probes presented a rupture of the body after 1,652,000 cycles for a maximum tensile stress near to 780MPa. This result was considered a point outside the curve, because its breakdown stress was below the almost horizontal line, which represents the infinite life tensile stress and also for having been the only specimen that broke when subjected to load 7.5 kg.

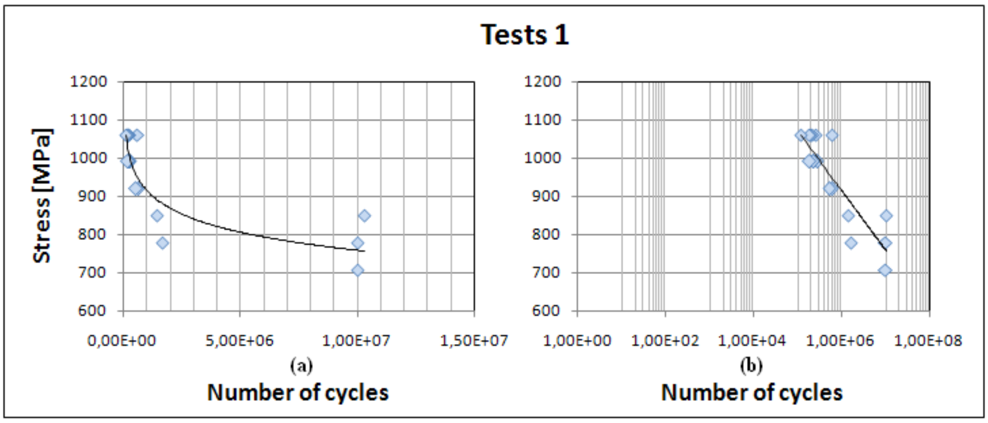



Figure 3. Wöhler curves for tests 1: (a) Linear scale; (b) Logarithmic scale.

The graphs of Fig. 4 show the results of the tests 2, performed on the axis 2 of the testing equipment. This curve begins to flatten slightly to 800MPa. An experiment at a tensile stress of 850MPa reached its end at 1,482,000 cycles.

This result is not considered an outlier because it is in the unstable region of the curve, where occurs the transition from finite to infinite life and several specimens with this stress have been tested.

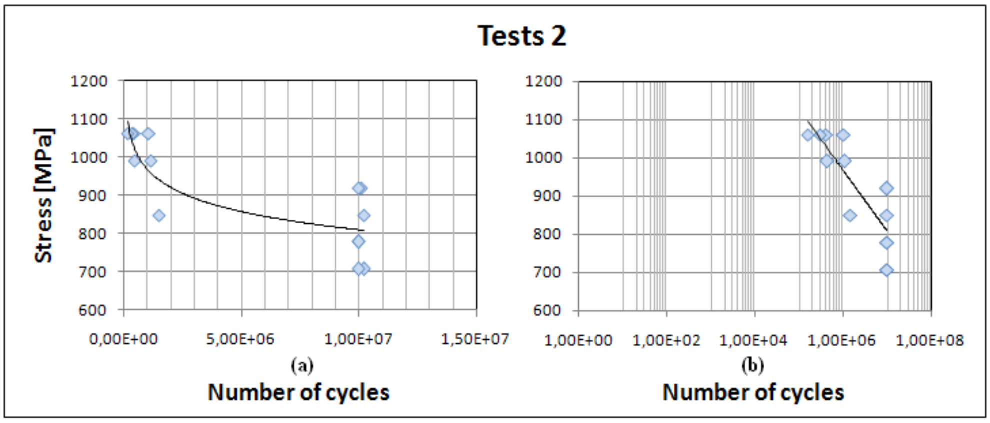



Figure 4. Wöhler curves for tests 2: (a) Linear scale; (b) Logarithmic scale.

The results of tests 3, carried on axis 3, are shown in Fig. 5. This curve does not exhibit atypical points, all of which are presented in compliance in the curve plotted, i.e. without much discrepancy between a result and another.

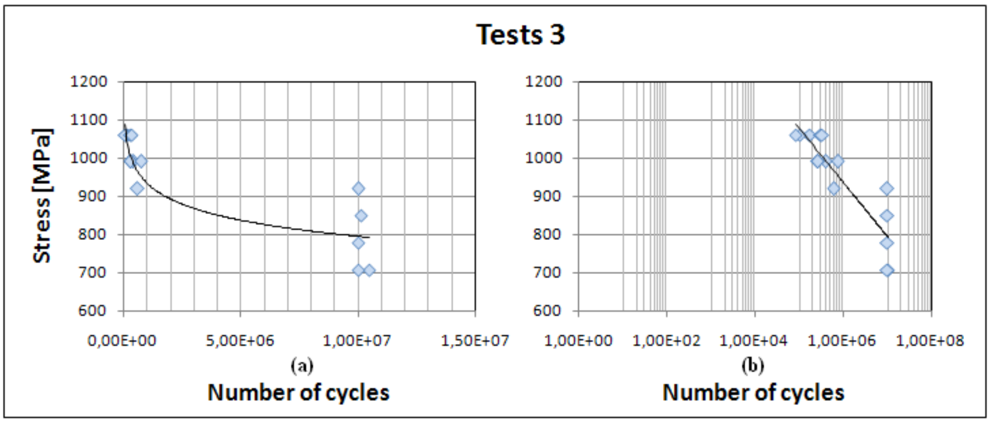



Figure 5. Wöhler curves for tests 3: (a) Linear scale; (b) Logarithmic scale.

Figure 6 presents the results of tests 4, produced on axis 4. This graph is very similar to that shown earlier in Fig. 5, since there are no points far from the curve delineated. In addition they present the same transition of limited to infinite life, where the stress is equal to 780MPa and the number cycles, 10,000,000.

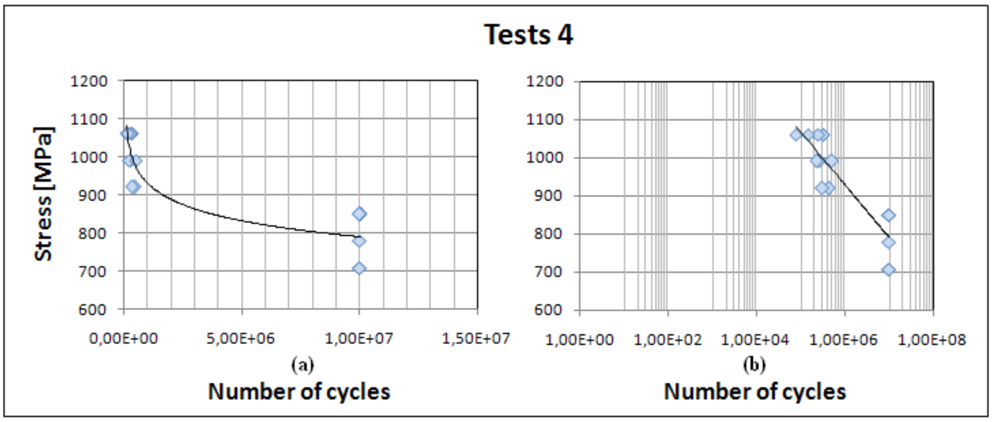



Figure 6. Wöhler curves for tests 4: (a) Linear scale; (b) Logarithmic scale.

The tests 5 were performed on axis 5, and its data are shown in the graph of Fig. 7. On this axis, the points with the greatest discrepancy between them refer to a tensile stress of 920MPa, where the curve begins to be slightly horizontal.

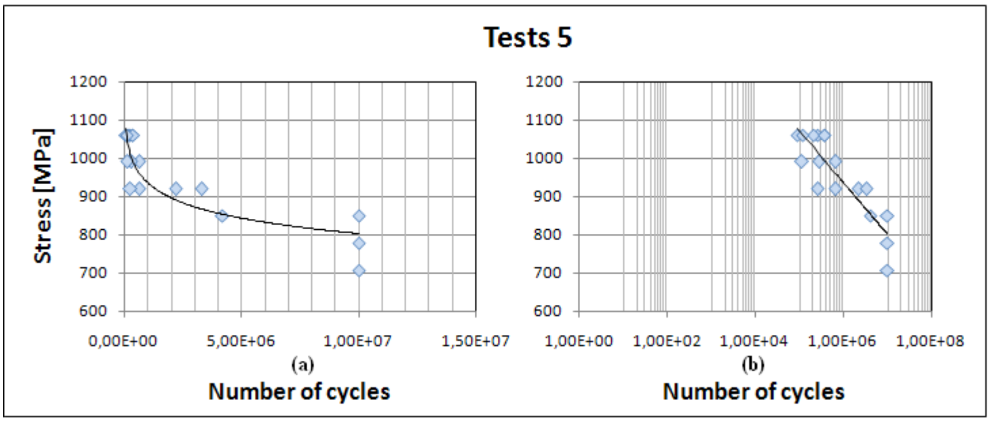



Figure 7. Wöhler curves for tests 5: (a) Linear scale; (b) Logarithmic scale.

In the graph of Fig. 8 are shown the results of tests 6, made on axis 6. This shows a little scatter of the results, even though this is the axis with the largest number of tested specimens. The small divergence found here refers, also, to transition region of the curve.

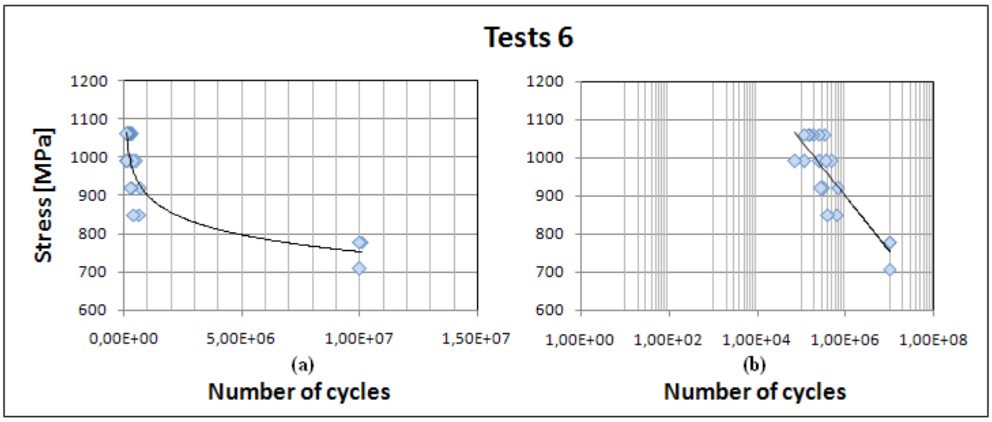



Figure 8. Wöhler curves for tests 6: (a) Linear scale; (b) Logarithmic scale.

All data collected during the validation of the fatigue bending test equipment on all axes, and all different loads are represented in order to present the general S-N curve behavior obtained with the tests. These results are shown in Fig. 9, where a large dispersion of data can be viewed.

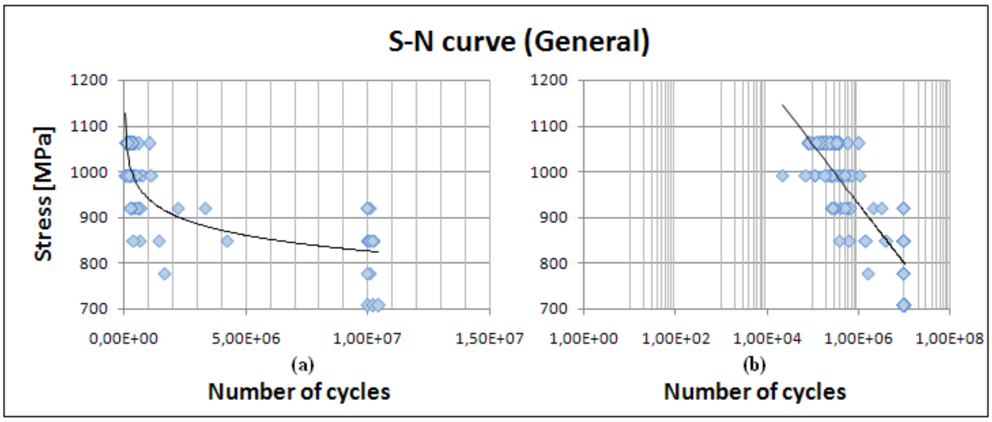



Figure 9. Mean results of the behaviour of the S-N curve for all tests: (a) Linear scale; (b) Logarithmic scale.

The dispersion of the data, according to Rosa (2002), is a feature that should be considered in every problem that is related to fatigue, especially when lives are over $10^4$ cycles. This happens as a consequence of nucleation which in turn is strongly influenced by metallurgical inhomogeneities, which are dispersed by the volume of material, randomly.

The distribution of fatigue life in any test is considered unknown and, in certain situations, quite complex due to the many factors of influence on it. To simplify the analysis, it is assumed in this practice that the logarithm of fatigue lives are normally distributed. That is, it is assumed that the dispersion of N is the same for both stress levels, high and low (Callister, 2005; Rosa, 2002).

According to Callister (2005), the greater the magnitude of the stress, the lower the number of cycles that the material can withstand before breaking. The S-N curve tends to become horizontal at higher values of N, because below the limit stress, fatigue limit, the fatigue failure does not occur. This fatigue limit represents the highest value of floating stress that will not cause failure for an essentially infinite number of cycles.

The same author further states that there is always a considerable dispersion of fatigue data, i.e. a variation in the value N measured for a number of samples tested on the same tensile stress level, which may lead to a significant uncertainty when the fatigue limit is being considered. The dispersion of the results is a consequence of the sensitivity of fatigue to a number of test parameters that are impossible to control precisely (Callister, 2005).

## 4. CONCLUSION

The rotating bending fatigue tests conducted on small specimens made of drawn and CNC machined SAE 1020 steel show that regardless of the axis on which the test is performed and regardless of the load applied, the influence of the equipment on the results can be disregarded. Thus, the device meets the requirements of a rotating bending test.

What about the occurrence of the dispersion of results, according to Callister (2005) and Rosa (2002), it is common in fatigue tests. The authors say the results of fatigue tests are characterized by wide dispersion of results due to factors such as variations in the dimensions of the test bodies and the surface finish, not homogeneity of the material, test conditions for each specimen and machine precision level assays.

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## 6. RESPONSIBILITY NOTICE

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