Comparison of uncertainty in fatigue tests obtained by the Monte Carlo method in two softwares

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Abstract: The Supplement 1 to the “Guide to the expression of uncertainty in measurement” indicates the Monte Carlo method for calculating the expanded uncertainty. The objective of this work is to compare the measurement uncertainty values obtained via Monte Carlo method through two commercial softwares (Matlab® and Crystal Ball®) for the parameter 'adjusted strain', obtained from fatigue tests. Simulations were carried out using different number of iterations and different levels of confidence. The results showed that there are short differences between the measurement uncertainty values generated by different software.

Keywords: Fatigue, Measurement, Uncertainty, Monte Carlo.

1. INTRODUCTION

The fatigue phenomenon represents more than 90% of failures in service components built with metallic materials [1]. Fatigue can be defined as the process of progressive localized permanent structural change occurring in material subjected to conditions which produce fluctuating stresses and strains at some point or points and may culminate in cracks or complete fracture after a sufficient number of fluctuations [2].

The value of the fixed strain is determined from the proof strength considering the surface roughness of the metallic material, and its determination is critical for indicating the tension effectively suffered by the material during cyclic loading.

The Monte Carlo method consists in applying an artificial sampling technique that operates numerically complex systems with independent input variables [3]. Different software may be used to generate pseudo-random numbers and used for the application of Monte Carlo simulation [4].

The Monte Carlo method is especially recommended for the input variables of uncertainty calculations with arbitrarily large values, measurement models with high nonlinearity and complexity, asymmetric distributions of the input quantities and probability distribution function associated with non-Gaussian a dominant component [5]. In such cases, the uncertainty estimation by the Monte Carlo method tends to be more representative than the ISO / GUM.

The number of iterations is an important factor in obtaining reliable results of the Monte Carlo method, such that the greater the number of simulations, the better the analysis of the results. However, the larger the number of iterations, the greater the computational work may make the use of very slow or even impracticable method. In general, results to one or two significant figures. [5]

Thus, the main objective of this study is to determine the uncertainty expanded to the 'adjusted strain' fatigue tests determined through two commercial softwares: Matlab® and Crystal Ball®, for two different confidence levels in different numbers of iterations.

2. 1 METHODOLOGICAL PROCEDURES

In this study, 36 test specimens of AISI 316L material were prepared for testing at three stress levels (480 MPa, 500 MPa and 520 MPa) and three different levels of roughness (Ru1, Ru2 and Ru3, according to Table 1).

Table 1. Preparation of the surface of the specimens.

Roughness	Surface Preparation
Ru1	Sanding with sandpaper water # 800 and polishing with diamond paste 6 microns
Ru2	Sanding with sandpaper water # 500, free polishing
Ru3	Sanding with sandpaper water # 320, free polishing

The fatigue specimens were tested on a servo hydraulic testing machine with 100 kN load capacity. For the tests, we used a frequency of 20 Hz, fatigue ratio 0.1 and as failure criterion to complete rupture of the specimen.

The measures of surface roughness were made on a roughness tester, being held five measures in the area of interest, with the help of a fixing system for the specimens. The Brinell hardness test (HB) were conducted five (5) measurements for each specimen.

2.1. Description of the mathematical model to determine the 'adjusted strain'

In the fatigue test, the value of the proof strength is changed due to the influence of surface roughness. Thus, the 'adjusted strain' (σ_{corr}) determined by multiplying a correction factor ($C_{\sigma,\ R}$) for the proof strength (σ_{test}) described in Equation 1.

$$\sigma_{corr} = C_{\sigma,R} . \sigma_{test} \qquad (1)$$

One of the simplest methods for determining the correction factor ($C_{\sigma,R}$) is the method described by FKM-Guideline guide [6] as shown in Equation 2.

$$C_{\sigma,R} = 1 - a_r . \log(R_z) . \log\left(\frac{2.S_{t,u}}{S_{t,u,\min}}\right) \qquad (2)$$

The values of a_r and $S_{t,u,\min}$ depends on the material and heat treatment to which the material is subjected and the value of $S_{t,u}$ is the actual resistance of the mechanical component. Thus, considering the values for stainless steel, the equation 2 can be rewritten as equation 3, and only function of surface roughness (R_z) and hardness HB.

$$C_{\sigma,R} = 1 - 0{,}22 . \log(R_z) . \log(0{,}014973.(HB)) \qquad (3)$$

The 'adjusted strain' is then determined based on a normal probability distribution and the estimation of measurement uncertainty of value is accomplished through the Monte Carlo method, based on the values of the lower limit (L_i) and the upper limit (L_s) of each variable [7], whereas the standard deviation for the construction of the probability distribution curve.

Finally, Monte Carlo simulations were performed for the estimation of measurement uncertainty of the test, comparing the values obtained by two commercial softwares (Matlab® and Crystal Ball®), two levels of confidence (95.45% and 99.73%) and two iterations numbers (10^5 and 10^6).

3. RESULTS AND DISCUTIONS

Table 2 shows the results obtained for 10^5 iterations and table 3 show results for 10^6 iterations were $\bar{x}$ represents the mean values of adjusted stress and U represents the measurement uncertainty.

Table 2. Measurement uncertainty values for 'adjusted strain', with 10^5 iterations.

Confidence level of 95.45%					
Software		Matlab®		Crystal Ball®	
Parametric		$\bar{x}$	U	$\bar{x}$	U
480 MPa	Ru1	491.10	7.38	491.09	7.37
	Ru2	480.48	2.79	480.48	2.79
	Ru3	469.65	3.34	469.66	3.34
500 MPa	Ru1	501.79	7.70	501.78	7.75
	Ru2	494.05	8.56	494.03	8.59
	Ru3	489.39	6.91	489.41	6.94
520 MPa	Ru1	526.11	5.69	526.13	5.67
	Ru2	514.16	13.07	514.19	12.99
	Ru3	506.81	6.65	506.81	6.65
Confidence level of 99.73%					
Software		Matlab®		Crystal Ball®	
Parametric		$\bar{x}$	U	$\bar{x}$	U
480 MPa	Ru1	491.11	11.05	491.09	11.06
	Ru2	480.49	4.18	480.48	4.18
	Ru3	469.65	5.04	469.66	5.01
500 MPa	Ru1	501.80	11.58	501.78	11.62
	Ru2	494.00	12.78	494.03	12.88
	Ru3	489.40	10.36	489.41	10.41
520 MPa	Ru1	526.11	8.50	526.13	8.51
	Ru2	514.16	19.61	514.19	19.48
	Ru3	506.80	9.96	506.81	9.98

Table 3. Measurement uncertainty values for 'adjusted strain', with 10^6 iterations.

Confidence level of 95.45%					
Software		Matlab®		Crystal Ball®	
Parametric		$\bar{x}$	U	$\bar{x}$	U
480 MPa	Ru1	491.12	7.40	491.12	7.40
	Ru2	480.49	2.79	480.49	2.79
	Ru3	469.65	3.35	469.65	3.35
500 MPa	Ru1	501.78	7.70	501.78	7.69
	Ru2	494.04	8.55	494.03	8.53
	Ru3	489.40	6.91	489.41	6.93
520 MPa	Ru1	526.12	5.68	526.11	5.67
	Ru2	514.16	13.20	514.12	12.80
	Ru3	506.79	6.66	506.80	6.65
Confidence level of 99.73%					
Software		Matlab®		Crystal Ball®	
Parametric		$\bar{x}$	U	$\bar{x}$	U
480 MPa	Ru1	491.12	11.09	491.12	11.10
	Ru2	480.49	4.18	480.49	4.18
	Ru3	469.65	5.03	469.65	5.03
500 MPa	Ru1	501.79	11.55	501.78	11.54
	Ru2	494.04	12.82	494.03	12.80
	Ru3	489.41	10.37	489.41	10.39
520 MPa	Ru1	526.11	8.52	526.11	8.51
	Ru2	514.16	19.75	514.12	19.20
	Ru3	506.80	9.98	506.80	9.97

The influence of the level of confidence in the uncertainty calculation was expected, because the higher the confidence level, the larger the covered area under the probability curve. For greater confidence level, the greater the uncertainty of the measurement value. It was also observed that for higher confidence levels, the greater the difference between the results obtained by comparing the different software.

The group of specimens with strain of 520 MPa and Ru2 presented great dispersion of the experimental results of surface roughness. It emphasizes the importance of the surface preparation, which must be suitable in order to avoid errors due to the machining marks. Surface roughness is a key factor in resistance to dynamic forces, this happens because of the fact that the indents act as surface tension concentrators.

It was used a numerical routines for each software to calculate the expanded uncertainty. Furthermore, there is a difference in methodology in the generation of random numbers used by each software by changing the shape of the probability distribution curve of the measurand. Still, the difference between software was much lower than the difference caused by other significant factors such as the condition tested and the confidence level.

It can be experimentally checked that the computational time to perform the simulations are different between the two softwares. The implementation way of each numerical routine, allows Crystal Ball® how fast than Matlab®. Using a desired level confidence of 95% confidence, the execution of 200,000 iterations can be considered enough [4].

4. CONCLUSIONS

The results showed that the higher the confidence level, the greater will be the expanded uncertainty of measurement values. Proportionally, these values suffer major influences of the software when used by larger magnitudes confidence level.

Differences between the measurement uncertainty of results were observed between the software when compared under the same simulation conditions. Most likely, these differences are due to the generation of random numbers and also due to the parameters initially determined based on the probability distribution curve.

However, even with the differences caused by each software, in most strain conditions, the values have been within the acceptable error as described in the calibration certificate of the cell load class 1 (acceptable error is <1%) used in the fatigue test. Nevertheless, these differences can be considered or not, depending on the project requirements to run or standard used in the development of fatigue test.

4. REFERENCES

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