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EXPERIMENTAL STUDY OF THE INFLUENCE OF SMALL DEFECTS ON FATIGUE LIFE IN LOW CARBON STEEL

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Abstract. *This work investigates the effects of small defects in fatigue life on SAE 1020 low carbon steel. For this, the experimental program developed consists of a set of uniaxial fatigue tests in smooth specimens and specimens with three types of defects - cylindrical defect Ø0.42 mm, cylindrical defect Ø0.75 mm and cylindrical shallow defect - in order to obtain S-N curves for each case. Based on the results obtained in these analyzes, it was observed that when change any small defects characteristics - size and depth – the fatigue life is significantly affected. The specimens with defects Ø0.42 mm showed less influence, reducing the fatigue life of material between 48% and 60% in relation to smooth specimens. In general, for lower stress amplitudes, the effects of the small defects are correspondingly larger, for all analyzed cases.*

Keywords: *small defects, life estimation, low carbon steel.*

1. INTRODUCTION

Any section changes or discontinuities - grooves, surface faults, small defects or holes - in a structural element causes concentrations of stress in its vicinity (Dowling, 2013). The emergence of these stress concentrators is inevitable in any type of material and should be studied with greater attention, since the fatigue life of the mechanical elements possessing them is significantly reduced (Schönbaury, 2016).

With the development of metallurgy, the need to quantitatively evaluate the effects of small defects has become increasingly important, especially in the quality and durability of the material. Within this scenario, many works were developed with the purpose of understanding the influence of small defects on the limit of fatigue. One of the most complete works on the influence of defects on metals was made by Murakami and Endo (1983), who introduced the geometric parameter $\sqrt{area}$. Another method widely used to analyze this type of problem is the stress gradient, around the defect, that was applied by Nadot and Billaudeau (2006).

However, unlike studies reported in the literature - which are concerned with studying fatigue resistance when there is a small defect - this paper focuses on the influence of small defects in the fatigue life in low carbon steels.

For this study SAE 1020 steel was used, which is considered the one with the highest application in the metallurgical industry, since it has low cost and good mechanical characteristics such as ductility, weldability and machinability (Ueda, 2007). Among its several applications it is possible to highlight: laminates for automobiles, gears, axles, crankshafts and structural profiles

2. EXPERIMENTAL PROCEDURE

The material used in this experimental work was the SAE 1020 steel, that was submitted to a normalization process – heated at 950ºC for thirty minutes and cooled slowly in the open air – to relieve the residual stresses of the manufacturing process and to homogenize the grains.

The specimens, were extracted from extruded 5/8” bars, were machined with a diameter of 8 mm and a length of 40mm in the test section (Figure 1). After machining, the specimens were polished with 220 to 2500 grit papers. This procedure resulted in a surface roughness less than 0.2µm, as recommended by ASTM E606 / E606M (2012).

A monotonic tensile test was performed to obtain the Young modulus E = 209 GPa, the yield stress σ_Y = 345 MPa and ultimate tensile stress σ_U = 415 MPa. The measured Brinell hardness of the normalized material is 118 HB.

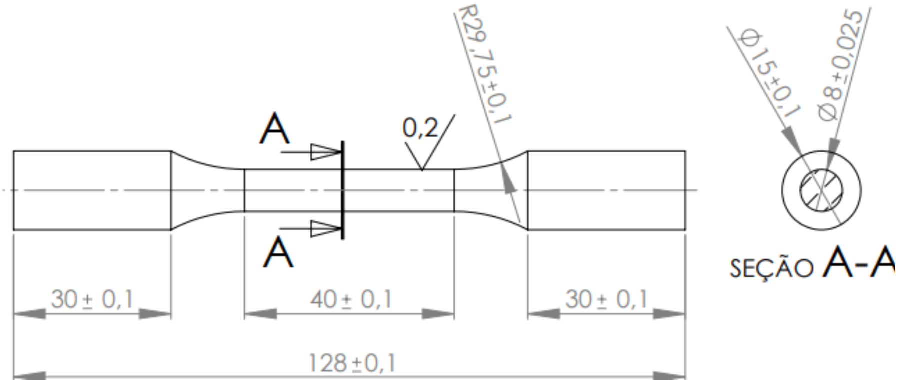
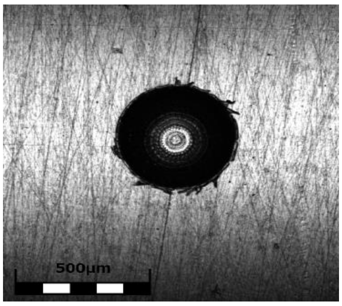
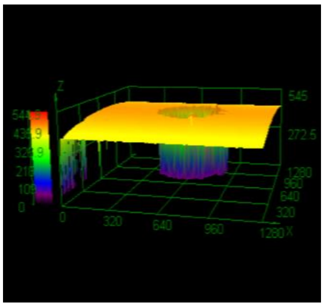
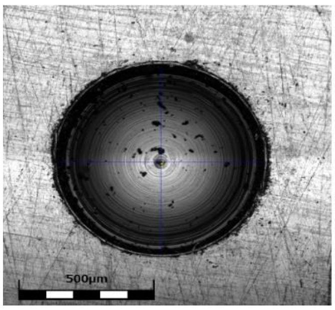
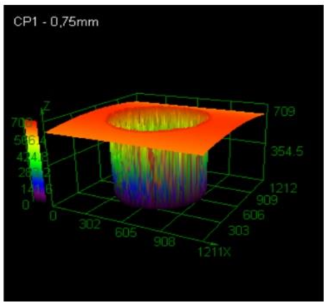
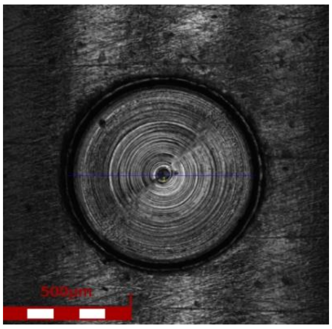
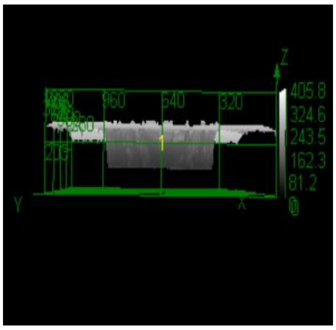


Figure 1. Geometry of the specimens used in the fatigue tests.

The small surface defects were milling in a machining center and their dimensions were measured using a confocal microscope applying a 200X magnification. Table 2 lists the features, shows the top and profiles of all defects studied.

Table 2 - Small defects parameters.

Small Defect		Description
		**Cylindrical Defects (CD 0.42)** Diameter = 0.42 mm Depth = 0.42 mm √area = 0.42 mm Shape: circular
		**Cylindrical Defects (CD 0.75)** Diameter = 0.75 mm Depth = 0.75 mm √area = 0.75 mm Shape: circular
		**Shallow Circular Defects (SD)** Diameter = 0.75 mm Depth = 0.20 mm √area = 0.42 mm Shape: circular

Mechanical fatigue tests were performed using a MTS810 TestFrame uniaxial servo-hydraulic machine, with load capacity of ± 100KN. The uniaxial tests were controlled by force, with loading frequency between 1.0 Hz and 10.0 Hz and ratio stress R = -1.

3. RESULTS AND DISCUSSION

The results obtained in tests with smooth specimens and specimens with three types of artificial small defects – SD, CD 0.42 and CD 0.75- are presented in Fig. 2.

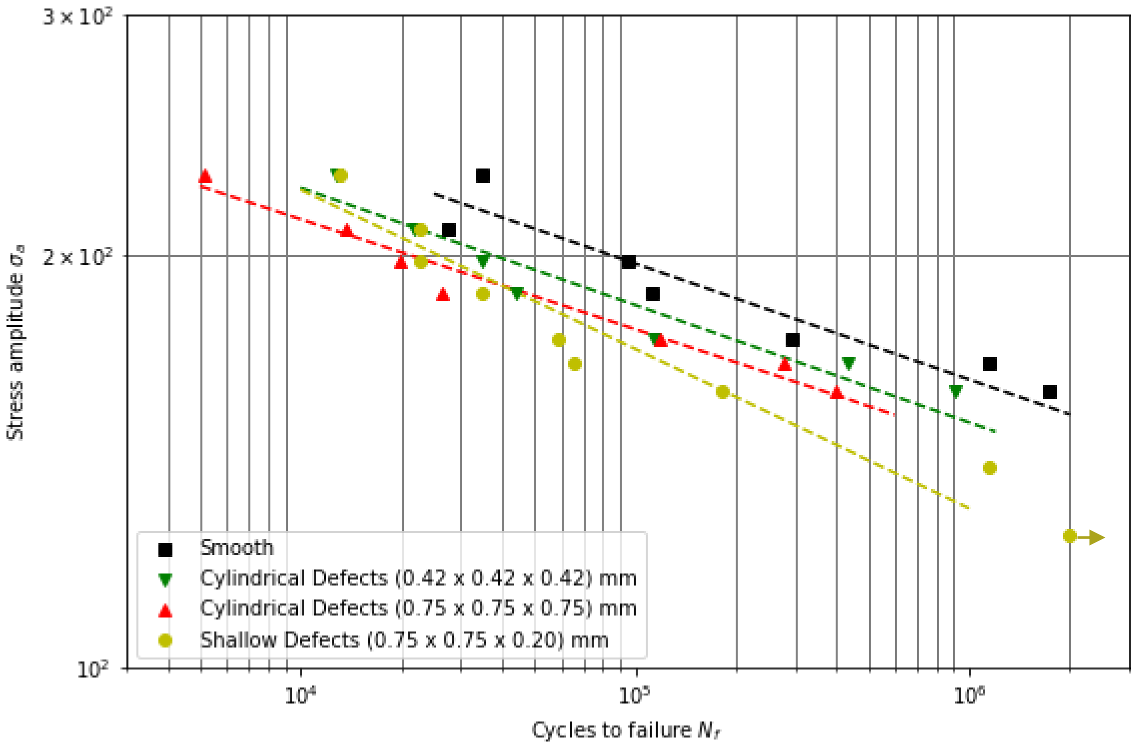


Figure 2. S-N curve of SAE 1020 steel

From the experiments, the fatigue strength coefficient (σ_f') and the fatigue strength exponent (b), for all specimens, are showed in Table 3.

Table 3. S-N curve constants.

Specimens	σ_f'	b	R^2
Smooth	524	- 0,0848	0,901
CD 0.42	494	- 0,0858	0,917
CD 0.75	446	- 0,0805	0,967
SD	699	- 0,1232	0,913

Quantitative analyzes show that specimens with shallow defects (SD), the reduction of the fatigue life varied between 60% to 95%, for stress amplitude of 230 MPa and 170 MPa, when compared with smooth specimens. In the case of specimens with defect CD 0.42, the reduction in fatigue life varied between 48% to 60%, for stress amplitude of 160 MPa and 230 MPa, while specimens with defects CD 0.75 reduce the fatigue life of material by a factor-of-four. It is noted, that for all types of defects, for higher stress amplitudes, the reduction of the fatigue life due to the defect is correspondingly smaller, which demonstrates that for shorter lives the material is less sensitive to changes in the characteristics of small defects.

When analyzing only defects that have a diameter equal to depth (CD 0.42 and CD 0.75), it is noted that specimens with defects CD 0.75 decreased the fatigue life by approximately 50% compared with specimens with defects CD 0.42. According to Murakami (2002), this difference occurs because the size of the defect affects the behavior of the material more intensively than the stress concentration factor (k_t) of the small defects, since the values of k_t for defects of similar geometries are approximately the same. In this case, the values of stress concentration factor for defect CD 0.42 and defect CD 0.75 are 2.9 and 3.2, respectively.

Comparing small defects with the same diameter but at different depths (CD 0.75 and SD), it is observed that specimens with shallow cylindrical (SD) defects have higher fatigue lives when it comes to stress amplitudes up to 190 MPa. However, this tendency changes for smaller stress amplitudes, that is, specimens with small defects DC 0.75 have a significantly higher lives than shallow cylindrical defect specimens. According to Nisitani and Endo (1985) the depth of the defect is what controls the behavior of the material. In this sense, the DC 0.75 cylindrical defect was expected to cause a greater reduction in fatigue life than the shallow cylindrical defect.

Regarding the initiation of the fatigue process, as observed by Murakami (2002), the cracks emanate from the superficial edges of the defects. However, when the depth of the defect is less than the diameter, cracks are more probably to start at the bottom of the defect (Beretta 2001), maybe due to a combination of the effects of two stress concentration regions in the defects: edge and bottom of the defect. However, it is only from a numerical analysis that such a supposition can be verified.

4. CONCLUSION

This study contributes to the knowledge on the fatigue in the presence of small defects in the sense that it focuses on fatigue life, whereas most of the studies on the subject focus on fatigue strength. From the analyzes performed in this study it is inferred that:

a) Small defects can reduce the fatigue life by factor-of-two in the case of defect CD 0.42 and by a factor-of-four in the case of the defect CD 0.75, for small defects with diameter equal depth. Further, the larger the stress amplitude, the larger the reduction in fatigue life produced by the defect of a given size.
b) Analyzes with small defects of the same diameter, but with different depths, indicate that the depth significantly influences the material behavior. Further studies should be conducted to better understand the significant reduction in fatigue life in this case.
c) Changes in the characteristics of small defects, whether in size or depth, have a different influence on the behavior of the material.

The results obtained in this study will subsidize the proposition of a mechanical model for the estimation of the fatigue life in the presence of small defects

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