Fatigue Limit Assessment of a Low Carbon Steel using Dixon's Up-And-Down and Infrared Thermography Methods

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Abstract. This paper provides results on the determination of the fatigue limit of a SAE 1020 steel using the conventional up-and-down method and the IR thermographic or Risitano's method applied to uniaxial cylindrical specimens under R = 0.1 load ratio. A more conservative value S_L = 177 MPa with a standard deviation of 0.5 MPa was obtained by IR thermography, which is ~14% lower than that determined by the up-and-down method, S_L = 204.7 MPa, with an standard deviation of 1.9 MPa, according to Dixon-Mood's statistical analysis.

Introduction

Experimental methods to measure fatigue limits (S_L) can be divided into two categories: conventional and accelerated tests. In general, conventional methods are very expensive and time consuming. The most traditional one uses a series of stress-life (*SN*) tests under fixed range loads up to lives between $10^6 - 10^7$ cycles for steels, cast irons, and Ti alloys, and up to $5{\cdot}10^8$ cycles for Al alloys. A large number of specimens, ranging from 12 to 24, is needed to obtain statistically reliable data according to ASTM E 739−10 standard for a specific interval of testing stress. On the other hand, accelerated tests have been developed to overcome the drawbacks of the conventional ones, such as the Dixon's up-and-down method [1]. It consists of a series of consecutive *SN* tests, where the load in the next test depends on whether the previous specimen failed or survived for a fixed number of cycles (e.g. for steels $10^6 < N < 10^7$). If a specimen fails, the load applied on the next test is reduced by one fixed step. If it survives, the next test load is raised by one step, and so on.

A simple procedure to measure the fatigue limit using IR thermography was proposed by Risitano et al. [2, 3]. The assessment of the fatigue limit considers the fatigue damage as an energy dissipation process that is accompanied by some temperature variation ΔT, [2, 3]. In the general procedure explained herein, a test specimen is subjected to a number of blocks of constant stress amplitude loading cycles, which are gradually increased until they eventually cause failure. This method significantly reduces the testing costs by decreasing the quantity of required specimens and by much shortening the testing time. Fatigue limits reported in literature using thermography analyses show variations up to ~20% when compared with the up-and-down method, depending on the material, equipment and testing conditions.

In this context, the aim of this work is to evaluate the fatigue limit of a SAE 1020 steel using the conventional up-and-down method and the IR thermographic or Risitano's method. The objective is, besides applying the Ristano's method with a new IR bolometer camera, to verify how close the fatigue limits are predicted by both methods and, in case of difference, to determine if the thermographic method consistently points to more conservative values. Moreover, results for other two materials, steel API 5L B and polycarbonate will be also reported in the conference, as well as the influence of test variables such as different test frequencies (*f*) and different stress ratios (*R*) on the results determined using the Risitano's method.

Materials and Experimental Procedure

Cylindrical specimens according with the ASTM E606M−12 standard were machined from a 76.2 mm x 12.7 mm flat bar of SAE 1020 steel. The evaluation of the fatigue limit using the up-and-down method was conducted testing 14 specimens, under constant amplitude stress-control at frequency of 57 Hz and stress ratio R = 0.1 ($R = \sigma_{min}/\sigma_{max}$, where σ_{min} and σ_{max} are the minimum and maximum stresses), using a 100 kN computer controlled servo-hydraulic machine. The fatigue limit was evaluated at the specified $N = 2{\cdot}10^6$ cycles.

Tests reported in this extended abstract using the Risitano's method employed three specimens machined according to ASTM E606M−12 standard. The specimens were painted with a thin layer of opaque black paint to increase their emissivity, making it close to the value of a black body along their whole surfaces. The specimens were also tested in the 100 kN INSTRON servo-hydraulic machine. During each fatigue test, the surface temperature of the specimen was recorded in real time by a bolometer thermocamera FLIR A655sc. It uses a focal plane array (FPA) of 640 x 480 pixels, space resolution of 17 microns, data acquiring frequency of 50 Hz on full frame configuration and spectral range from 7.5 to 14 μm, with sensitivity below 30 mK. For each specimen, the $\Delta T - \Delta\sigma$ curve was obtained, where ΔT is the difference between the maximum specimen surface temperature value (T_i) for each stress range level $\Delta\sigma_i$ and the reference temperature (T_r). The temperature data was acquired and analyzed using the ResearchIR software from FLIR. Based on the experimental methodology proposed in [3], the specimens were tested under stepped loading procedure, sequentially applied to each specimen at a constant amplitude force-control, with 15 Hz frequency and R = 0.1. At each step, the load was maintained fixed during blocks of $N = 1.5 \cdot 10^4$ cycles, a value that was large enough to make the specimens achieve a stable thermal behavior, as determined by preliminary tests.

Results and Discussion

Fatigue test results determined for the SAE 1020 steel using the Dixon's up-and-down method for R = 0.1 and $N \leq 2 \cdot 10^6$ are presented in Fig. 1.

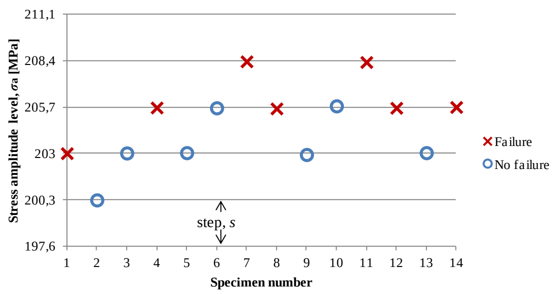

Figure 1. Fatigue test results for the SAE 1020 steel specimens; Dixon's up-and-down method for R = 0.1 and $N \leq 2 \cdot 10^6$

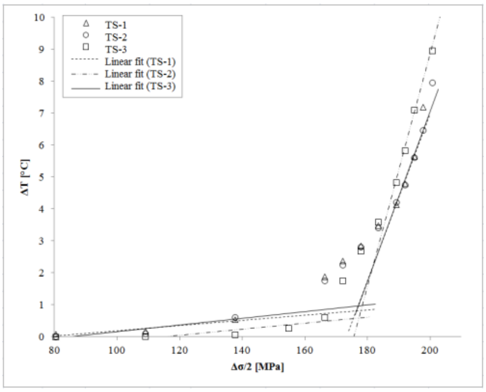

Figure 2. Fatigue limit evaluation of three test specimens (TS) of SAE 1020 steel tested by thermography, R = 0.1.

Plots of $\Delta T - \Delta\sigma$ for three tested specimens of SAE 1020 steel are shown in Fig. 2 in a way to apply the Risitano's method. At stresses below the fatigue limit, ΔT increases slowly with a constant rate $d(\Delta T)/d(\Delta\sigma/2)$. However, when the stress amplitude overcomes the fatigue limit value, the rate $d(\Delta T)/d(\Delta\sigma/2)$ suddenly increases and two linear trends in the plots are clearly defined. The fatigue limit can be determined by a graphical or numerical method to enhance the intercept of the two linear fit of the experimental data points. Therefore, the fatigue limit at R = 0.1 evaluated with this method is 177 MPa with a standard deviation of 0.5 MPa. The intrinsic error associated with the measures acquired using this method is in the range of less than 10%. In the methodology proposed, it is pointed out that many characteristic errors of fatigue tests can be eliminated. Indeed, the fatigue limit could be measured with only one specimen, but in practice it is recommended to report the mean value of the fatigue limit of three specimens. Three specimens are enough due to the fact that thermography data showed lower scattering (< 10%).

Conclusions

Two methods were presented for the evaluation of the fatigue limit of a given plate of SAE 1020 steel. Similar values for the fatigue limit at R = 0.1 were measured using conventional up-and-down method and IR thermography. A more conservative value S_L = 177 MPa with a standard deviation of 0.5 MPa was obtained by IR thermography, which is ~14% lower than that determined by up-and-down method, S_L = 204.7 MPa with an standard deviation of 1.9 MPa, according to Dixon-Mood's statistical analysis. Further research on fatigue limits, *SN* fatigue curves, test frequency dependence, test stress ratio influence, as well as results determined for specimens of API 5L Grade B steels and annealed Polycarbonate. All these results will be presented in the conference.

References

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