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Fatigue limit evaluation of various martensitic stainless steels with new robust thermographic data analysis

R. De Finis*, D. Palumbo, F. Ancona, U. Galietti

Politecnico di Bari, Department of Mechanics, Mathematics and Management, Viale Japigia, 182, 70126 Bari, Italy

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ABSTRACT

Thermography represents an important tool to study fatigue behaviour of materials.

In this work, the fatigue limit of martensitic and precipitation hardening stainless steels has been determined with thermographic methods. Despite their use in corrosive and cryogenic environments, there is a data lack in literature concerning the study of fatigue behaviour.

The peculiarity of these materials is the brittle behaviour: therefore, during fatigue tests the characteristic small deformations determine small changes of temperature. Thus, to properly determine the fatigue limit of aforementioned stainless steels, a more accurate setup is necessary in order to correctly detect surface temperature of specimens due to dissipation heat sources.

In literature, different procedures have already been proposed to evaluate the fatigue limit from thermal data but very few works lead to an early detection of dissipation process which can obtain a further reduction of overall testing time. The aim of the paper is to propose a new robust thermal data analysis procedure for estimating fatigue limit of stainless steels in automatable way.

1. Introduction

The aim of the work is to study the fatigue behaviour of martensitic stainless steels and in particular to propose a new procedure to assess the fatigue limit with thermography in automatable way. The tested stainless steels are: X4 Cr Ni Mo 16–5–1, ASTM A 182 F6NM, AISI 422 (with martensitic lattice), 17–4PH (precipitation hardening). The “Stair Case” method has been carried out in order to obtain a comparison with thermography results for ASTM A 182 F6NM and 17–4PH.

In recent years, thermography has been used to study fatigue behaviour of materials. In particular, temperature or thermal sources were related to the fatigue damage of material and can then be used to assess the fatigue limit [1–15].

Conventional and traditional methods generally used to obtain the fatigue limit in respect to thermographic techniques are dramatically time-consuming. For example, the “Stair case method” [16] requires more than 15 specimens and 2/3 months of a hydraulic loading machine to characterize a material, compared to maximum one week needed by thermographic techniques. Moreover, the analysis of fatigue damage with thermal methods can provide additional information about the position and dimension of cracks and plasticization area of material [1–13].

In literature, the analysis of fatigue damage with thermography has been performed considering different approaches that can be summarized as follows:

- measurement and monitoring of the superficial temperature [3,4,8–13],
- evaluation of the thermal heat sources (dissipative sources evaluation) [1,2,14,15,17],
- evaluation of the thermoelastic sources and phase thermoelastic signal (TPA method) [7–9].

In Luong’s work [1] an energetic approach was used to describe the heat production mechanism correlated to intrinsic dissipation in material. Monitoring temperature variations during the test, it is possible to evaluate the dissipations and to find the fatigue limit of material by means of a graphic method.

A similar approach has been proposed by Morabito et al. [3] and Risitano and Risitano [4]. It is based on a suitable procedure in which the specimen is subjected to stress amplitudes which are gradually increased until failure. When the stress amplitude is higher than fatigue limit, surface temperature of the specimen increases and then reaches a plateau value. The fatigue limit of material can be assessed either considering the heating rate

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* Corresponding author. Tel.: +39 3334350585.

E-mail addresses: rosa.definis@poliba.it (R. De Finis), davide.palumbo@poliba.it (D. Palumbo), francesco.ancona@poliba.it (F. Ancona), umberto.galietti@poliba.it (U. Galietti).

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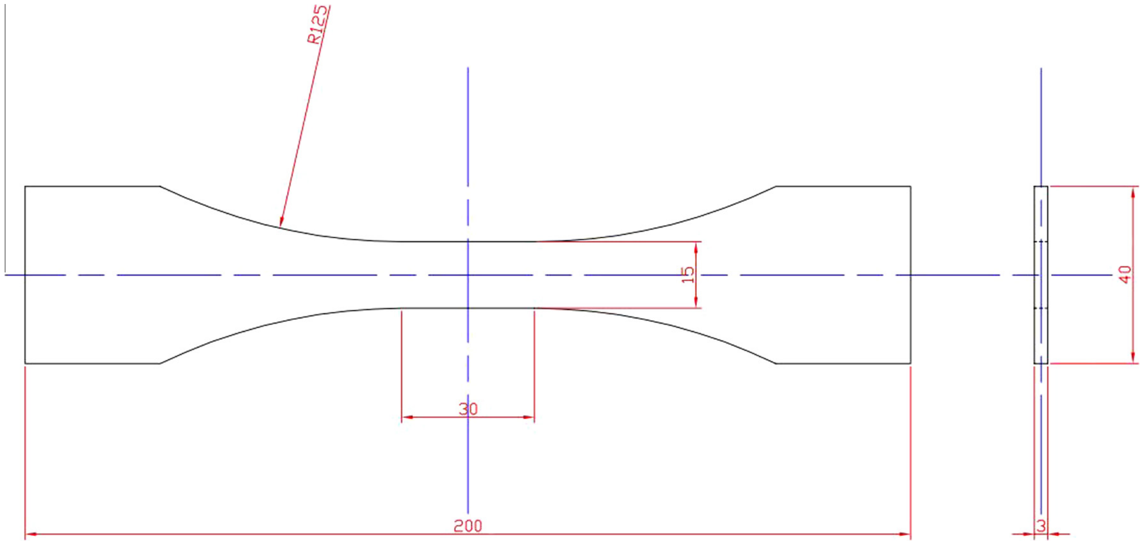
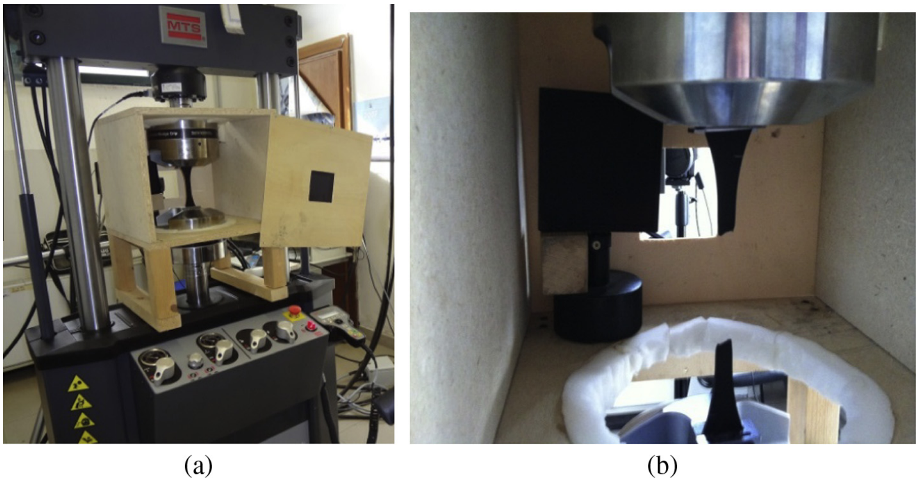


Fig. 1. Dimensions (mm) and geometry of specimens.



(a) (b)

Fig. 2. (a) Loading machine, insulated chamber, specimen and (b) inside of insulated chamber: specimen, black body and IR camera.

Table 1
Loading table in terms of stress (semi-amplitude $\Delta\sigma/2$): the first specimen of each material.

Loading step	AISI 422 $\Delta\sigma/2$ (MPa)	17–4 PH $\Delta\sigma/2$ (MPa)	ASTM A 182 F6NM $\Delta\sigma/2$ (MPa)	X4 Cr Ni Mo 16–5–1 $\Delta\sigma/2$ (MPa)
1	80.0	140.0	25.0	25.0
2	100.0	160.0	45.0	45.0
3	125.0	170.0	65.0	65.0
4	130.0	180.0	85.0	85.0
5	135.0	185.0	100.0	105.0
6	137.5	190.0	115.0	120.0
7	140.0	195.0	130.0	135.0
8	142.5	200.0	140.0	150.0
9	145.0	205.0	150.0	165.0
10	147.5	210.0	160.0	180.0
11	150.0	215.0	170.0	190.0
12	152.5	220.0	175.0	200.0
13	167.5	225.0	180.0	207.5
14	182.5	235.0	185.0	215.0
15	197.5	250.0	190.0	222.5

($\Delta T/\Delta N$) or the steady-state temperature. Both procedures involve in linear regression straight lines in order to approximate thermal data and to find the fatigue limit.

Considering a local energy approach, different works are based on the evaluation of thermal sources to describe damage phenomena due to fatigue. These works [14,15,17] consider the heat