Data Article

Fatigue data for laser beam powder bed fused 17-4 PH stainless steel specimens in different heat treatment and surface roughness conditions

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ARTICLE INFO

Article history:
Received 2 March 2019
Received in revised form 21 June 2019
Accepted 26 June 2019
Available online 4 July 2019

Keywords:
Laser beam powder bed fusion (LB-PBF)
17-4 PH stainless steel
Fatigue behavior
Heat treatment
Surface condition

ABSTRACT

This article presents the data demonstrating the synergistic effect of surface roughness and heat treatment on the fatigue behavior of 17–4 PH stainless steel (SS) fabricated via laser beam powder bed fusion (LB-PBF) [1]. Two sets of specimens, in as-built and machined surface conditions, were heat treated using five different recommended procedures for 17-4 PH SS by ASTM A693. Axial fully-reversed fatigue tests (R = -1) were conducted on heat treated as-built and machined specimens. The stable hysteresis stress–strain data, as well as the maximum and minimum stress and strain values for the cycle in a log10 increment are included for all conducted fatigue experiments. In addition, fractography images are provided for selected set of specimens.

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DOI of original article: https://doi.org/10.1016/j.ijfatigue.2019.02.039.
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The experimental data presented in this article obtained from axial fully-reversed (R = -1) strain-controlled fatigue tests on LB-PBF 17-4 PH SS specimens. All the specimens (i.e., with as-built or machined surface) were fabricated via laser beam powder bed fusion (LB-PBF) technique. Square bars were further machined to make fatigue specimens with the geometry and dimensions similar to the as-built specimens. Five different heat treatments were applied to all specimens. Axial fully-reversed (R = -1) strain-controlled fatigue tests were carried out following ASTM E606 standard [3].

Synergistic effects of surface roughness and heat treatment on the fatigue performance of LB-PBF 17-4 PH SS are demonstrated. Fractography is performed to reveal the fracture mechanisms of LB-PBF 17-4 PH SS specimens in as-built and machined surface conditions.

The generated datasets specifically provide information on the effect of heat treatment on cyclic deformation and fatigue behavior of LB-PBF 17-4 PH SS. Synergistic effects of surface roughness and heat treatment can also be learned from the presented data. Fractography analysis images demonstrate the effect of surface roughness and/or internal defects, such as gas entrapped pores, on the fatigue failure mechanisms. Modelers can use these datasets to calibrate and validate their models.

1. Data

The experimental data presented in this article obtained from axial fully-reversed (R = -1) strain-controlled fatigue tests on LB-PBF 17-4 PH SS specimens. All the specimens (i.e. with as-built or as-built specimens were fabricated via laser beam powder bed fusion (LB-PBF) technique. Square bars were further machined to make fatigue specimens with the geometry and dimensions similar to the as-built specimens. Five different heat treatments were applied to all specimens. Axial fully-reversed (R = -1) strain-controlled fatigue tests were carried out following ASTM E606 standard [3].

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1. Data

The experimental data presented in this article obtained from axial fully-reversed (R = -1) strain-controlled fatigue tests on LB-PBF 17-4 PH SS specimens. All the specimens (i.e., with as-built or
machined surface conditions) were heat treated based on the heat treatment procedures shown in Fig. 1. CA stands for Condition A, which is a solution heat treatment procedure (i.e. heat treating at 1050°C for half an hour, followed by air cooling to room temperature). Some specimens were initially subjected to CA heat treatment procedure to investigate the effect of solution heat treatment on the fatigue behavior. Fatigue data for the two sets of specimens, as-built and machined surface conditions, for all heat treatments are listed in Table 1 and Table 2, respectively. The data included herein are based on the experimental results provided in a previous publication by present authors [1]. All the data can be downloaded from the Mendeley Dataset (https://doi.org/10.17632/c3dp75g5x9.1).

| Heat treatment procedure | Specimen ID | Strain amplitude, $\varepsilon_a$ (mm/mm) | Frequency (Hz) | Reversals to failure, $2N_f$ |
|--------------------------|-------------|------------------------------------------|----------------|-----------------------------|
| H900                     | SP_6        | 0.0010                                   | 5              | 636,952                     |
|                          | SP_5        | 0.0010                                   |                | 624,146                     |
|                          | SP_4        | 0.0020                                   | 2.5            | 36,956                      |
|                          | SP_3        | 0.0020                                   |                | 35,568                      |
|                          | SP_2        | 0.0030                                   | 1.75           | 14,164                      |
|                          | SP_11       | 0.0030                                   |                | 10,052                      |
|                          | SP_7        | 0.0030                                   |                | 48,588                      |
|                          | SP_8        | 0.0040                                   | 1.25           | 3026                        |
|                          | SP_10       | 0.0040                                   |                | 2898                        |
| H1025                    | SP_14       | 0.0010                                   | 5              | 1,188,840                   |
|                          | SP_19       | 0.0010                                   |                | 645,562                     |
|                          | SP_12       | 0.0020                                   | 2.5            | 99,010                      |
|                          | SP_13       | 0.0020                                   |                | 64,446                      |
|                          | SP_15       | 0.0020                                   |                | 79,458                      |
|                          | SP_16       | 0.0030                                   | 1.75           | 18,612                      |
|                          | SP_17       | 0.0030                                   |                | 22,732                      |
|                          | SP_20       | 0.0040                                   | 1.25           | 9116                        |
|                          | SP_18       | 0.0040                                   |                | 8630                        |
| CA-H900                  | SP_22       | 0.0010                                   | 5              | >10,049,222                 |
|                          | SP_36       | 0.0010                                   |                | >10,000,000                 |
|                          | SP_38       | 0.0015                                   | 3.3            | 297,378                     |
|                          | SP_39       | 0.0015                                   |                | 188,054                     |
|                          | SP_45       | 0.0015                                   |                | 499,102                     |
|                          | SP_21       | 0.0020                                   | 2.5            | 235,076                     |
|                          | SP_23       | 0.0020                                   |                | 128,050                     |
|                          | SP_25       | 0.0030                                   | 1.75           | 40,988                      |
|                          | SP_24       | 0.0030                                   |                | 31,438                      |
|                          | SP_27       | 0.0040                                   | 1.25           | 11,840                      |
|                          | SP_26       | 0.0040                                   |                | 7822                        |
| CA-H1025                 | SP_44       | 0.0015                                   | 3.3            | >10,693,604                 |
|                          | SP_43       | 0.0015                                   |                | >10,273,224                 |
|                          | SP_49       | 0.0020                                   | 2.5            | 177,810                     |
|                          | SP_50       | 0.0020                                   |                | 113,374                     |
|                          | SP_48       | 0.0030                                   | 1.75           | 43,952                      |
|                          | SP_47       | 0.0030                                   |                | 29,352                      |
|                          | SP_51       | 0.0040                                   | 1.25           | 10,540                      |
|                          | SP_52       | 0.0040                                   |                | 7426                        |
| CA-H1150                 | SP_46       | 0.0015                                   | 3.3            | >10,012,162                 |
|                          | SP_53       | 0.0015                                   |                | >10,002,396                 |
|                          | SP_41       | 0.0015                                   |                | 530,362                     |
|                          | SP_42       | 0.0015                                   |                | 339,506                     |
|                          | SP_28       | 0.0020                                   | 2.5            | 361,246                     |
|                          | SP_29       | 0.0020                                   |                | 300,064                     |
|                          | SP_30       | 0.0030                                   | 1.75           | 56,068                      |
|                          | SP_31       | 0.0030                                   |                | 49,962                      |
|                          | SP_32       | 0.0040                                   | 1.25           | 10,268                      |
|                          | SP_33       | 0.0040                                   |                | 9176                        |
Argon atomized 17-4 PH SS powder was utilized to fabricate specimens using EOS M290, a laser beam powder bed fusion (LB-PBF) system. All specimens were fabricated under argon shielding gas. Two sets of LB-PBF 17-4 PH SS specimens were considered in the design of experiment. First set was as-built specimens fabricated vertically to the final specimen geometry and dimensions, recommended by ASTM E606 [3] and shown in Fig. 2. The second set was fabricated as vertical square bars and later machined to the geometry and dimensions similar to the as-built specimens, shown in Fig. 2.

Each set of specimens were divided into five groups to go through five different heat treatment procedures [2]. The utilized heat treatments are schematically described in Fig. 1. Two groups of specimens from each set (i.e. as-built and machined surface conditions) went directly through the aging heat treatment of either H900 or H1025, as shown in Fig. 1(a). The other three groups went through intermediate heat treatments.

### Table 2
Summary of uniaxial fully-reversed ($R = -1$) fatigue test results for heat treated LB-PBF 17-4 PH SS specimens in machined (MA) surface condition [1].

| Heat treatment procedure | Specimen ID | Strain amplitude, $\varepsilon_a$ (mm/mm) | Frequency (Hz) | Reversals to failure, $2N_f$ |
|--------------------------|-------------|----------------------------------------|----------------|---------------------------|
| H900                     | SP_32       | 0.0020                                 | 2.5            | >10,485,384              |
|                          | SP_46       | 0.0020                                 |                | >10,012,062             |
|                          | SP_34       | 0.0025                                 | 2              | 454,602                  |
|                          | SP_33       | 0.0025                                 |                | 355,844                  |
|                          | SP_27       | 0.0030                                 | 1.75           | 176,086                  |
|                          | SP_28       | 0.0030                                 |                | 175,776                  |
|                          | SP_29       | 0.0040                                 | 1.25           | 38,230                   |
|                          | SP_30       | 0.0040                                 |                | 25,472                   |
| H1025                    | SP_44       | 0.0020                                 | 2.5            | >10,280,216              |
|                          | SP_41       | 0.0020                                 |                | >10,100,720              |
|                          | SP_40       | 0.0025                                 | 2              | 496,526                  |
|                          | SP_39       | 0.0025                                 |                | 303,788                  |
|                          | SP_36       | 0.0030                                 | 1.75           | 213,094                  |
|                          | SP_35       | 0.0030                                 |                | 203,538                  |
|                          | SP_38       | 0.0040                                 | 1.25           | 56,462                   |
|                          | SP_37       | 0.0040                                 |                | 55,118                   |
| CA-H900                  | SP_7        | 0.0020                                 | 2.5            | >10,614,228              |
|                          | SP_6        | 0.0020                                 |                | >10,596,648              |
|                          | SP_16       | 0.0025                                 | 2              | >10,772,058              |
|                          | SP_23       | 0.0025                                 |                | 820,176                  |
|                          | SP_4        | 0.0030                                 | 1.75           | 291,556                  |
|                          | SP_5        | 0.0030                                 |                | 266,272                  |
|                          | SP_25       | 0.0030                                 |                | 255,006                  |
|                          | SP_2        | 0.0040                                 | 1.25           | 59,286                   |
|                          | SP_1        | 0.0040                                 |                | 54,014                   |
|                          | SP_3        | 0.005                                  | 1              | 12,048                   |
| CA-H1025                 | SP_22       | 0.0020                                 | 2.5            | >10,603,816              |
|                          | SP_20       | 0.0025                                 | 2              | >10,109,402              |
|                          | SP_21       | 0.0025                                 |                | 2,496,340                |
|                          | SP_15       | 0.0030                                 | 1.75           | 1,394,730                |
|                          | SP_18       | 0.0030                                 |                | 254,274                  |
|                          | SP_14       | 0.0040                                 | 1.25           | 51,348                   |
|                          | SP_13       | 0.0040                                 |                | 39,764                   |
| CA-H1150                 | SP_12       | 0.0020                                 | 2.5            | >10,887,458              |
|                          | SP_42       | 0.0020                                 |                | >10,044,094              |
|                          | SP_17       | 0.0025                                 | 2              | 1,488,706                |
|                          | SP_19       | 0.0025                                 |                | 383,866                  |
|                          | SP_10       | 0.0030                                 | 1.75           | 232,096                  |
|                          | SP_11       | 0.0030                                 |                | 185,542                  |
|                          | SP_9        | 0.0040                                 | 1.25           | 46,852                   |
|                          | SP_8        | 0.0040                                 |                | 33,746                   |
through the initial CA (i.e. solution heat treatment) before applying the subsequent again heat treatments, shown in Fig. 1(b), designated as CA-H900, CA-H1025, and CA-H1150.

Axial fully-reversed \((R = -1)\) constant amplitude strain-controlled fatigue tests were performed within the range of 0.001 mm/mm-0.004 mm/mm strain amplitudes using an MTS servo hydraulic test machine with a sinusoidal waveform input. For each strain amplitude level, a minimum of two fatigue tests were performed to ensure the consistency of results. Plastic deformation was negligible; therefore, all cyclic tests were switched to force-controlled mode after a few thousands of cycles. The test frequency was attuned for each test to maintain a constant average strain rate among all experiments. Fatigue tests that reached \(10^7\) cycles were stopped and marked as run-out tests. Tables 1 and 2 summarize the fatigue data for as-built and machined specimens, respectively. Fractography analyses were performed to elucidate the crack initiation and failure mechanisms for the as-built and machined specimens.

**Acknowledgements**

This material is based upon the work supported by the U.S. Naval Air Systems Command (NAVAIR).
Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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