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Experimental Setup for Fatigue Testing of Additively Manufactured Specimens

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Abstract. Poor fatigue life is a huge issue of additively manufactured parts, despite the unique qualities characterizing this manufacturing process (such as low waste of material and geometry freedom). Fatigue life is strongly affected by both surface defects and internal defects, metal AM is characterized by extremely poor surface quality, internal porosities and lack of fusions. For this reason, many researchers investigated methods to improve manufacts quality. The most promising methods are surface finishing treatments and thermal treatments which provide an enhancement of fatigue behavior. A focal point of the research should be evaluating the respective contribution of surface treatments and thermal treatments. In order to evaluate the effectiveness of surface treatment, it is necessary to highlight the surface quality contribution in terms of fatigue life thus a specific testing method is necessary. Rotating beam fatigue test fits this requirement because each point of the specimen's surface is subjected to the maximum stress. The aim of this work is to present the experimental setup for rotating beam fatigue testing that has been used to evaluate the fatigue behavior of AM SLM IN718 specimens.

Introduction

Mechanical validation of additively manufactured parts is crucial nowadays since AM is considered being one of the most disruptive manufacturing processes. AM is an eco-friendly process, enables the realization of complex geometries and is characterized by high efficiency. However, this new manufacturing method is characterized by some drawbacks: poor surface quality, internal porosity and uncontrolled microstructure are some of them.

Many researchers dedicate their work to overcoming these problems and different solutions have been proposed, such as hot isostatic pressing, heat treatments and surface finishing processes [1, 2].

Enhancing fatigue behavior of AM parts would be a significant outcome for industrial applications, accordingly research on the above mentioned drawbacks is necessary since they are detrimental for fatigue behavior [3].

It has been demonstrated that HIP treatments may be barely ineffective in terms of fatigue life if the specimens' print quality is high. In this case, no internal/few internal defects are present before the heat treatment therefore HIP isn't enhancing the internal density furthermore. A poor fatigue behavior must be related to poor surface quality [4].

In other cases, despite of the surface quality improvement, manufacts still exhibit poor fatigue behavior because internal defects may initiate cracking [5].

Rotating fatigue beam testing is considered to be one of the most testing methods in order to highlight the only surface quality contribution. This result is believed to depend on the particular stress gradient of the rotating bending test: all points of the surface are subjected to the maximum load range, if the surface quality is strongly affecting fatigue behavior then the weakest point of the surface always initiates cracking. While in four point bending tests and cantilever tests, only top and bottom fibers are subjected to the maximum load, meaning that the weakest point of the surface may never be sufficiently stressed in order to initiate cracking.

As research on AM parts surface quality influence on fatigue life is fundamental, a prototypal rotating beam fatigue testing machine has been designed and produced [6] in collaboration with a local company (Sophìa High Tech) in order to carry out customized rotating beam fatigue testing, as well as fatigue validation of additively manufactured parts.

Experimental Setup

Comparison between the different classic fatigue testing methods has already been investigated [7] and rotating fatigue beam testing is considered to be the most reliable test since fatigue strength measured by means of rotating bending tests is lower than that from other types of tests (four point bending and cantilever tests).

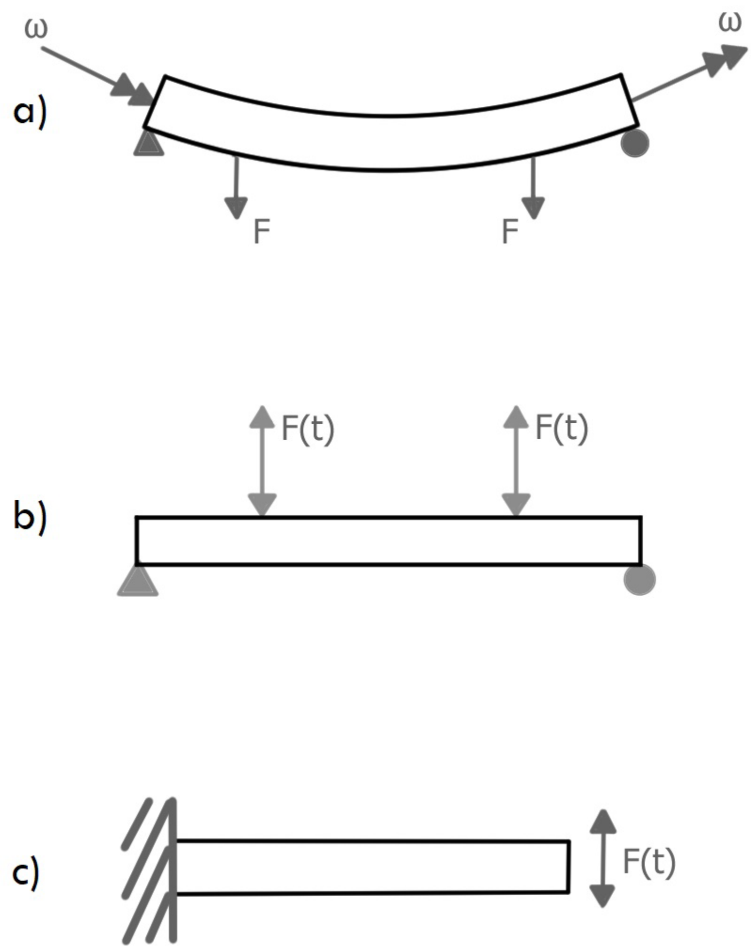

Fig. 1 Schematic representation of rotating beam fatigue test (a), four point bending test (b) and cantilever test (c)

For this reason, a prototypal rotating beam fatigue testing machine has been designed, built and validated through different fatigue tests carried out on known materials (mainly steels).

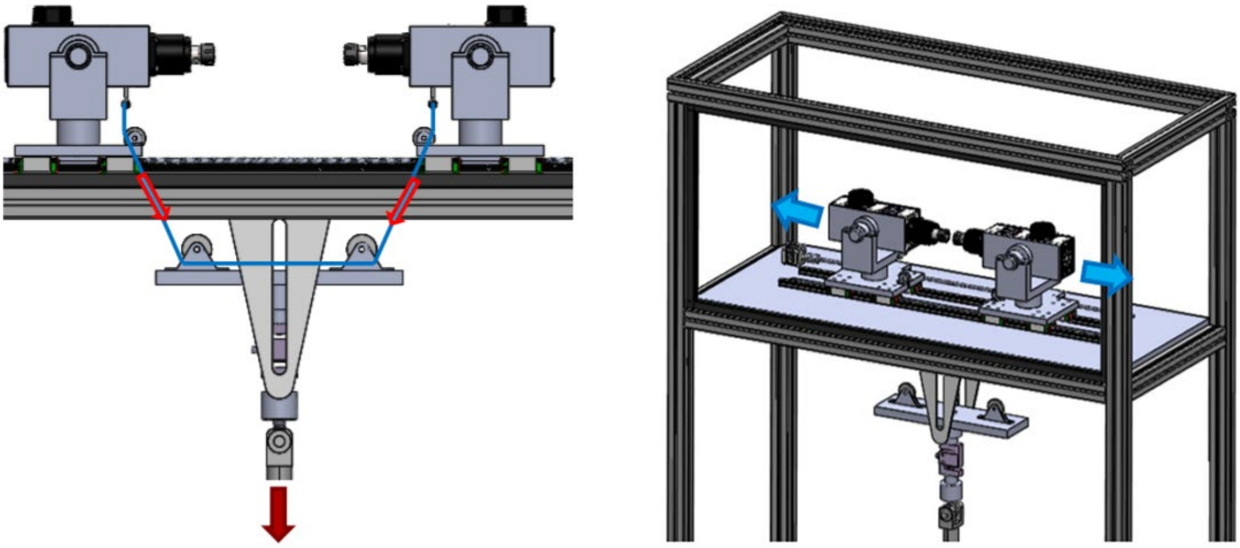

Fig.2 Rotating beam fatigue testing machine design

The machine has been designed including the ISO1143 standard prescriptions, aiming to provide a wide investigation spectrum in terms of rotational speed (ranging from 900 to 12000 r.p.m.), load (actuator full scale is 5 kN) and specimen dimensions (distance between mandrels is adjustable and ranges from 50 to 220 mm, diameter of the specimen is also flexible and can vary from 2 to 20 mm).

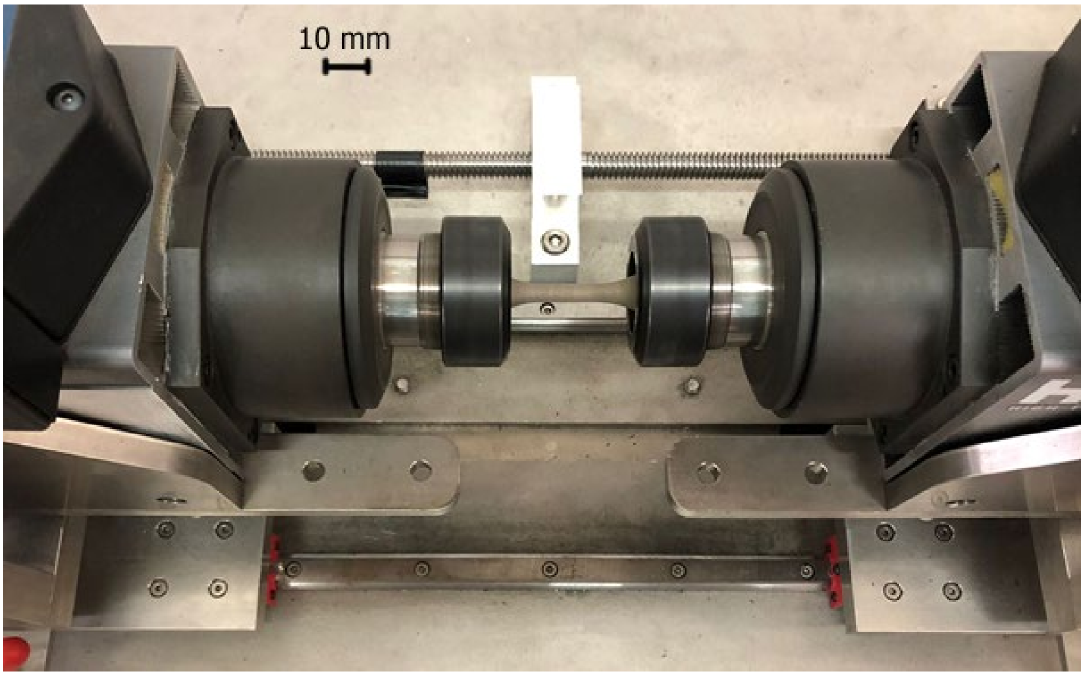

Fig.3 Prototypal RBF testing machine operating.

A batch of additively manufactured IN718 specimens has been produced using the SLM Printer Concept Laser m2 in order to carry out fatigue testing.

The specimens were built in vertical directions, which is considered being the worst case scenario for additively manufactured parts in terms of fatigue behavior when it comes to considering the build direction influence [3, 8] and their geometry was determined according to ISO 1143 prescriptions.

Fig.4 SLM IN718 vertically built specimens.

The specimen geometry was designed according to ISO1143 standard, print process parameters were 192 W of power, 0.15 mm of spot size, 600 mm/s of scanning speed for the body and 1600 mm/s of scanning speed for the contour while the measured roughness was Ra = 9 µm.

Results and Discussion

Fatigue tests have been carried out at different stress amplitude values in order to obtain the S-N relation. Results show poor fatigue life of additively manufactured SLM IN718 specimens and have been analyzed and plotted as Wöhler Curve (fig.5).

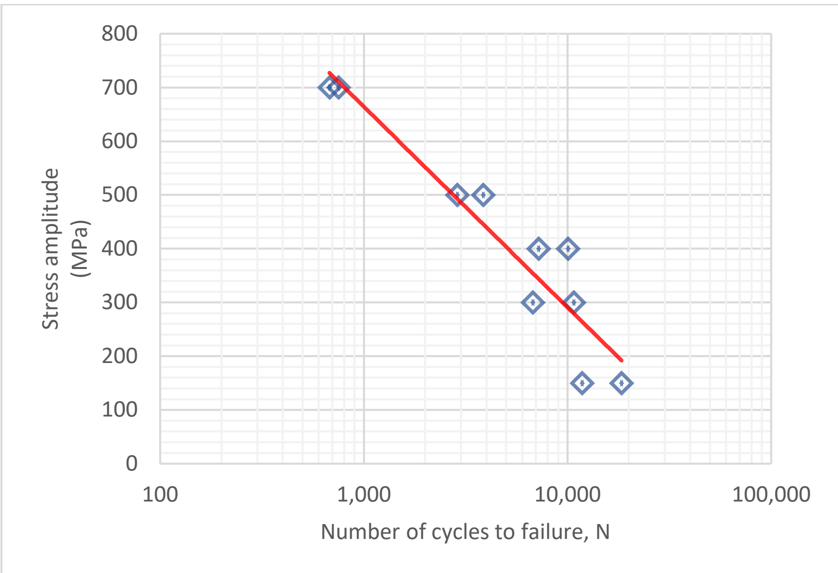

Fig.5 S-N Diagram for IN718 specimens.

The testing campaign evidenced no fatigue limit, this result can be related to the poor surface quality and the vertical build direction which are both detrimental for fatigue life behavior. The cracking initiates from the surface and leads to failure in a short time if compared to literature results [9].

Further investigation is needed to identify the presence of internal defects as micro voids and lack of fusion and their contribution in terms of fatigue life.

Eventually, to improve fatigue behavior, surface roughness must be lowered, for example using a surface treatment [5, 10–12] while thermal treatments can reduce the influence of internal defects [13, 14].

Conclusions

Tests generated an appropriate data set and were capable of highlighting the surface quality contribution on fatigue life behavior in fact cracking initiates from the surface and propagates to the internal part of the specimen.

Fatigue testing of additively manufactured parts is an open field in research, starting from previous observations, further investigation on the manufacts quality is needed. While thermal treatments influence, such as HIP, has been widely discussed and considered to be a good solution in order to improve the microstructure and reduce/cancel voids and lack of fusions, research on surface treatments is still open. In addition, when the print quality is extremely high, internal defects influence is barely detectable while surface quality remains low.

Among the most innovative and promising surface finishing treatments, chemical surface finishing, laser polishing and fluidized bed machining are the ones belonging to this line of research.

Investigation on the above mentioned surface finishing techniques has to be carried out, the main focus is to relate fatigue behavior to the surface roughness and compare the fatigue performances of the respective treatments.

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