SHIMADZU

Application News

Shimadzu Ultrasonic Fatigue Testing System

No. SCA_300_001

Very High Cycle Fatigue (VHCF) Assessment of Laser Additive Manufactured (LAM) AlSi12 Alloy

■ Introduction

Selective laser melting (SLM) is a laser additive manufacturing process where parts are additively manufactured using powder material with the aid of laser energy. Three-dimensional CAD model is provided as an input to the SLM machine, which scans the geometry after slicing the geometry into 2D layers. The laser energy selectively melts the powder particles at the desired location of the component to be manufactured. The unique manufacturing capability of SLM process makes it suitable for aerospace, automotive and biomedical applications. Several alloys like aluminum, titanium, steel and nickel-based alloys have been processed by SLM technique [1,2]. Although the fatigue strength diminishes for SLM processed materials in the "as-built" condition due to the process-inherent surface roughness, fatigue performance after post-processing is suitable for many applications in the aviation and medical industry [1].

Contrary to the previous assumption that the materials do not fail under fatigue if the applied stress is below the so-called fatigue limit; with the availability of the novel very high cycle fatigue (VHCF) testing techniques, it has been found that materials do fail under fatigue loading even when the stresses are below the conventional fatigue limit, suggesting the non-existence of such a limit [3,4]. Some alloys of both lattice types (bcc and fcc) show a change in crack initiation site from surface to subsurface in a region from HCF to VHCF [5].

■ Experimental methodology

The test samples of AlSi12 alloy were manufactured using a commercially available SLM system in an inert environment using argon gas. The details of the processing setup and parameters can be viewed in [1]. Quasi-static tensile tests were carried out according to ISO 6892-1:2009. Continuous load increase tests were carried out starting at low stress amplitude of 30 MPa. Stress amplitude was increased slowly at a rate of 10 MPa / 10^4 cycles. Load increase tests and constant amplitude testes were carried out at a frequency of 20 Hz. The results of process optimization, quasi-static properties, high cycle fatigue properties and the measurement methodology for characterization of process-induced defects are published in [2,6]. Two types of configurations are investigated in this study. For the batch I, no pre-heating of the base plate was applied; whereas samples of batch II were manufactured with a base plate heating (BPH) at 200 °C.

Very high cycle fatigue (VHCF) tests were carried out on an ultrasonic fatigue testing system at a frequency of 20 kHz. Fig. 1 shows the overview of the USF-2000 testing system by Shimadzu (http://www.shimadzu.de/usf-2000) and Fig. 2 explains the detailed principle of the test setup. Piezoelectric crystal is used in the actuator, which resonates at a fixed frequency of 20 kHz. In the ultrasonic fatigue testing system, vibrations are designed so that the longitudinal waves transmitted through the solid body resonate.

Fig. 1: Overview of the ultrasonic fatigue testing system USF-2000 by Shimadzu

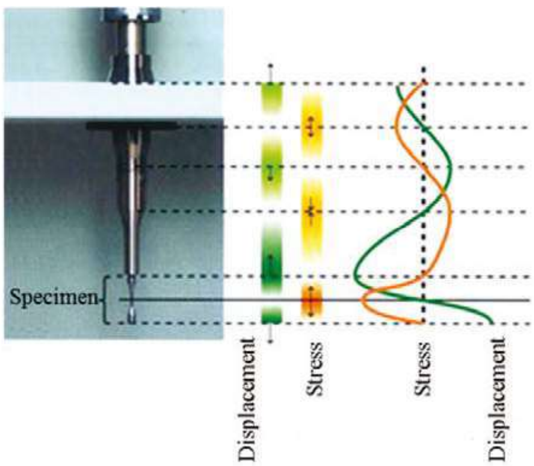

Fig. 2: Functional principle of specimen loading at ultrasonic fatigue testing system USF-2000

The specimen with geometry shown in Fig. 3 is clamped only at one threaded end on USF and is free at the bottom end. The specimen is designed in a way that maximum stress is experienced at the middle of the specimen and the maximum displacement occurs at the free end of the specimen. To eliminate the temperature effect due to high test frequency, the specimens were cooled with compressed air during tests and the tests were performed at a pulse-pause ratio of 50:50 i.e. the system was set to resonance for 200 ms and then stopped for the next 200 ms to cool down.

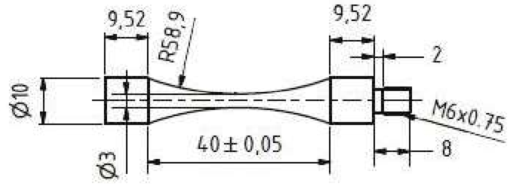

Fig. 3: Specimen geometry for ultrasonic fatigue tests

Experiments for determination of the fatigue strength at 10^9 cycles were performed according to stair-case method. If a specimen at ultrasonic frequency failed at less than 10^9 cycles, the stress amplitude is decreased by 5 MPa for the next experiment. If the specimen did not fail at 10^9 cycles, the stress amplitude was increased by 5 MPa in the subsequent test. Failure of the specimen is based on the change is resonance frequency. When the micro-crack leads to final fracture, the natural frequency of the system reduces than the operating frequency of the system and the test is terminated.

■ Results

Fig. 4 shows exemplary surface micrographs for the two investigated batches. The remnant porosity is viewed as only the gas porosity. A difference in the pore fraction of the samples without and with base plate heating is observed. In the samples with base plate heating, large size gas pores are absent which are very critical for fatigue performance. The reduction of large pores is attributed to the de-gassing in the manufacturing chamber due to pre-heating.

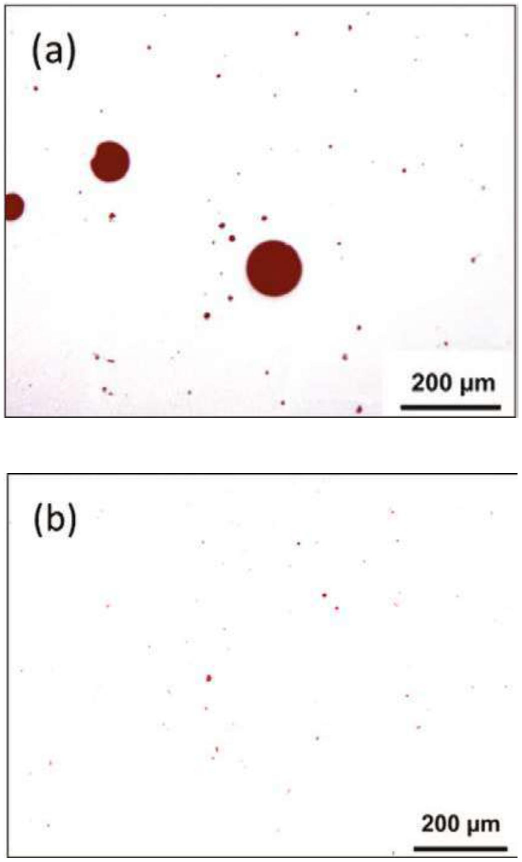

Fig. 4: Exemplary surface micrograph for sample without base plate heating (a); and with base plate heating (b)

Fig. 5 represents S-N curves for batches I and II in the region from high cycle fatigue (HCF) to very high cycle fatigue (VHCF). Experiments showed that the fatigue fracture occurs beyond high cycle fatigue region in both batches. The results of the experiments indicate that fatigue strength in very high cycle regime of samples manufactured with base plate heating is about 45% higher than fatigue strength of sample without base plate heating. Fatigue strength at one giga cycle for batches I and II is 60.5 ± 4.7 MPa and 88.7 ± 3.3 MPa, respectively. This increase in strength is attributed to elimination of the micro pores.

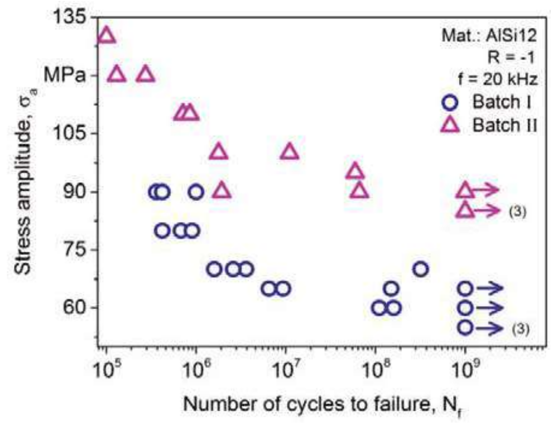

Fig. 5: S-N characterization for ultrasonic fatigue testing results

■ Outlook

New developments in testing machines enabled to go beyond the previously known limits of knowledge. This opens the door towards more intensive testing in the most realistic conditions. The new capabilities in testing machines shall provide researchers with powerful tools to further investigate the effect of processing parameters on the resulting functional performance in a wide range.

■ References

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LAAN-A-AG-E018

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Application News
No.i254

Material Testing System

Compression After Impact Testing of Composite Material

Introduction

Carbon fiber reinforced plastic (CFRP) has a higher specific strength and rigidity than metals, and is used in aeronautics and astronautics to improve fuel consumption by reducing weight. However, CFRP only exhibits these superior properties in the direction of its fibers, and is not as strong perpendicular to its fibers or between its laminate layers. When force is applied to a CFRP laminate board, there is a possibility that delamination and matrix cracking will occur parallel to its fibers. Furthermore, CFRP is not particularly ductile, and is known to be susceptible to impacts. When a CFRP laminate board receives an impact load, it can result in internal matrix cracking and delamination that is not apparent on the material surface. There are many situations in which CFRP materials may sustain an impact load, such as if a tool being dropped onto a CFRP aircraft wing, or small stones hitting the a CFRP wing during landing. Consequently, tests are required for these scenarios. One of these tests is compression after impact (CAI) testing. CAI testing involves subjecting a specimen to a prescribed impact load, checking the state of damage to the specimen by a nondestructive method, and then performing compression testing of that specimen. This article describes CAI testing performed according to the ASTM D7137 (JIS K 7089) standard test method.

Measurements Taken Before Compression After Impact Testing

(1) Impact Test

The impact test involved dropping a 5 kg steel ball striker formed with a 16 mm diameter hemispherical point in the middle of the specimen. The specimen is fixed in place with four toggle clamps. The standard test method states that avoiding a second impact is preferred, so impact testing was performed with a mechanism that prevented second impacts. The impact energy recommended in the standard test method is 6.67 J per 1 mm of specimen thickness. For the purpose of comparison, the test was performed at four impact energies of 6.7, 5.0, 3.3, and 1.7 J per 1 mm thickness. Information on the specimen used is shown in Table 1. The test setup is shown in Fig. 1, and test conditions are shown in Table 2.

Table 1 Specimen Information

Dimensions [mm]	: 100 × 150 × 4.56
Lamination Method	: [45/0/−45/90] $_{ns}$
Material	: T800, 2252S-21

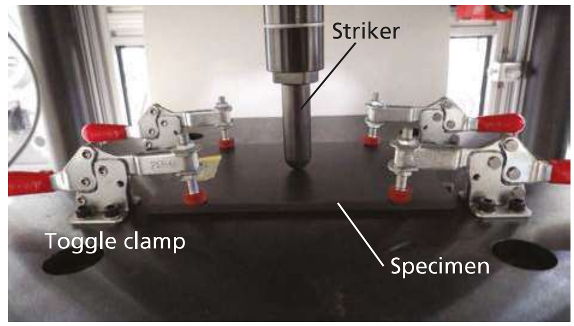

Fig. 1 Impact Test Setup

Table 2 Impact Test Conditions

Impact Energy	: 30.5, 22.9, 15.2, 7.6 [J]
No. of Tests	: n = 4

(2) Non-Destructive Inspection

After the impact test, the delamination area and maximum delamination length that resulted inside the laminate board were measured by nondestructive analysis. An ultrasonic flaw detection device is normally used for the non-destructive inspection step of CAI testing. The standard test method states that if ultrasonic flaw detection shows damage is present across more than half the width of the specimen, edge effects cannot be ignored and lowering the impact energy should be considered. Fig. 2 shows the setup for ultrasonic flaw detection.

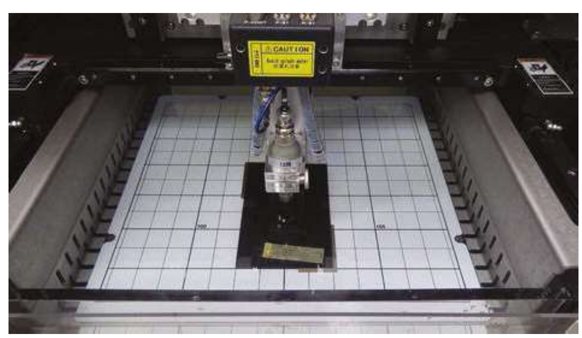

Fig. 2 Ultrasonic Flaw Detection