Reducing Low Cycle Fatigue Life Scatter of Additive Manufactured AlSi10Mg Using Laser Shock Peening

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Abstract

Additive manufactured (AM) alloys are still prone to critical manufacturing flaws, such as gaseous bubble entrapment. These defects can lead to early crack initiation reducing fatigue life and increasing scatter, especially when near surface. This research investigated the effect of femtosecond laser shock peening (FLSP) on the fatigue life of AM AlSi10Mg. Due to the low penetration of the FLSP, fatigue life remained consistent between treated and untreated specimens. Of equal importance though, the scatter was found to be reduced in the FLSP treated samples. From the high resolution DIC results, the average strain per grain in the untreated specimens showed a higher increase of strain from initial loading to final fracture as compared to the FLSP samples. Implementing the use of FLSP onto AM materials could lead to more consistent fatigue life despite the presence of porosity, leading to a path of easier certification and improved confidence in their behavior.

1. Introduction

AM has become a staple in the prototyping process and low volume manufacturing due to ability to produce near net shape complex part geometries in a relatively short amount of time. However, there are challenges with defects such as gaseous bubble entrapment. These defects become hyper critical as they get near the surface of the component [1]. The way in which the defects interact with the surface when surrounded by internal stresses is a concept which is relatively unexplored. The goal of this study was to examine the effects of laser shock peening on additively manufactured aluminum alloy, AlSi10Mg. A set of samples were post processed using a FLSP surface treatment with a laser pulse energy of 1 mJ and an overlap ratio of 70%. The residual stress from the FLSP was quantified using the contour method. Then strain-controlled fatigue experiments and stress-controlled fatigue experiments coupled with high resolution digital image correlation (HRDIC) was performed on both as-printed and LSP samples.

2. Results

The contour method was used to quantify the residual stresses produced by the FLSP process. This destructive measuring process is outlined in great detail by Prime *et. al* [2]. The residual stress quantification established the depth of the residual stress and magnitude of the compressive residual stress. The results show that the depth of compressive stress is approximately 0.5 mm and the maximum compressive stress was 746 MPa. With a depth of 0.5 mm this would be past the initial crust layer for the top and bottom specimens and extend into the bulk of the material and into the region of critical pores.

The fatigue specimens were electrical discharge machined from a singular block of AlSi10Mg. All specimens were tracked based on the location within the block and the surface crust from the AM process was kept on the top and bottom specimens. The strain-controlled fatigue experiments were run at strain amplitudes ranging from 0.05 - 0.4 % in tension-tension. Figure 1 shows the results from the low cycle fatigue experiments for the non-LSP samples and FLSP samples. The location within the build plate did not change the fatigue life of the non-LSP samples, therefore the FLSP samples were not labeled by location although all three locations were tested. The initial fatigue results indicate that the FLSP did not increased fatigue life as compared to the non-LSP samples. However, the results show a decrease in the scatter of the fatigue results.

A complementary set of stress-controlled experiments, with a force amplitude of 0.5 kN and a R ratio of 0.1, used a HRDIC technique coupled with EBSD results to analyze the strain fields within grains. The process of aligning and overlapping DIC images with EBSD aligns with the process used by Pataky *et. al* [3]. The analysis was performed for on both non-LSP and FLSP samples. A flower like microstructure, common in AM metals/alloys due to the grains growing in the melt pool direction, was observed in all samples. The average strain per grain were recorded for multiple cycle numbers throughout the fatigue experiment. The non-LSP samples have a lower average grain per strain, however, the standard deviation and range of strain averages was much higher than that of the FLSP sample. The higher variation and range of the average strain could help to explain how the fatigue scatter could be increased. There have been other instances where LSP decrease localized stress to help aid the fatigue life of samples [4]. It is currently proposed that the decreased variation in fatigue scatter is due to the residual stress present which decreases the critical effects of stochastic defects near the surface.

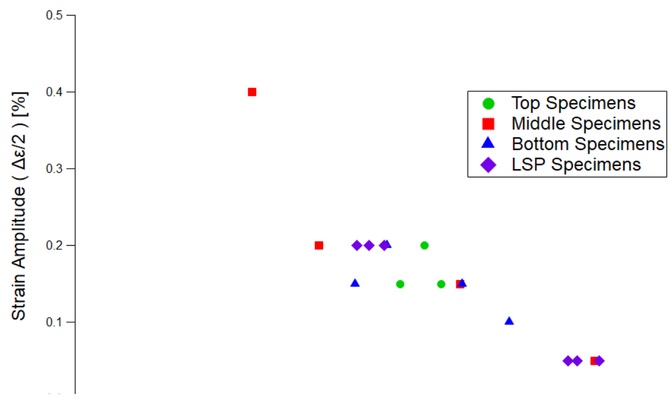

Figure 1. Strain Controlled Fatigue Results for both non-LSP, broken down into top, middle, and bottom samples, and FLSP samples of AlSi10Mg Specimens

3. Conclusions

FLSP was used to extend the fatigue life of AM AlSi10Mg. Although the results show that FLSP does not extend the fatigue life, the results indicate that the fatigue scatter can be reduced. HRDIC was conducted in conjunction with grain boundary locations from EBSD results. The results indicated that the decreased fatigue scatter correlated with the decrease in variance in the average strain per grain for a given grain size.

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