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Effects of Shot Peening on the Fatigue Strength of Parts Produced by Additive Manufacturing

WITH MORE THAN 55 YEARS of experience, FerroECOBlast® Europe, based in Dolenjske Toplice, Slovenia, is one of the global leaders in the field of surface treatment technologies. What makes them stand out from the crowd is their dedication to research and development. This study, performed by their R&D department in collaboration with the Jožef Stefan Institute—the leading scientific laboratory from Slovenia and Joanneum Research Centre from Graz—explores the effects of shot peening on additively manufactured parts.

Due to the outstanding growth of the additive industry (also known as 3D printing), new guidelines and requirements appeared in the surface treatment of unconventional structures and materials. Cold micro-forging, better known as shot peening, is a well-known surface treatment process, commonly used on machine parts in the most demanding industries such as aerospace and automotive. Shot peening improves the technological properties of machine parts and increases their lifetime.

The question arises as to what extent the porosity and resulting micro-cracks affect the mechanical characteristics of the 3D printed part and what can be done to improve it. Research is being conducted into various directions: annealing and the consequential change of the metal microstructure, compression/rolling and probably the most appropriate of all, a modern shot peening process. Since AM technologies are relatively new and the effect of shot peening on such machine parts has not yet been extensively researched, our company decided to conduct a study about the effects of shot peening on metal parts, manufactured by Additive Manufacturing.

TEST OVERVIEW

The different 3D printing processes facilitate the manufacturing of complex parts and prototype pieces, making it difficult to select a typical machine part manufactured using these processes as a test subject. We chose a common test piece that is often used to perform fatigue strength tests in laboratories. The test pieces were manufactured using the SLM (selective laser melting) process, also known as LPBF (Laser Powder Bead Fusion). As for materials, we selected three different frequently used metal alloys:

1. Aluminum Alloy AlSi10Mg
2. Maraging steel MS1 (DIN 1.2709)
3. Titanium Alloy Ti6Al4V

Figure 1: Test subject – 3D printed test piece
Left: Raw, untreated part • Right: Ground, before shot peening

HEAT TREATMENT

The 3D printed test pieces were cleaned of residual dust and oxides, followed by annealing and aging. The test pieces were then ground to their final dimension to ensure dimensional accuracy and better technical properties of the test parts. Each of the selected materials required a different heat treatment as seen in Table 1.

Table 1: Test pieces heat treatment parameters for each selected material

	Process	Temperature (°C)	Time (min)
AlSi10MG	Annealing	270	90
MS 1	Aging	490	360
Ti6-Al4	Annealing	650	180

MECHANICAL TREATMENT

Since the test pieces produced by AM didn't have a sufficiently precise shape after heat treatment, mechanical post-processing, namely grinding, was required to ensure the precise geometry needed for testing. This way, we obtained accurate results during permanent dynamic strength testing. All tested parts were manufactured according to the standard shape and dimensions of common laboratory test pieces.

SHOT PEENING

The last process before testing was shot peening. The selected parameters were empirically determined according to the most common parameters in practice for each particular type of conventional base material. To determine the most appropriate method, three shot peening methods with different types of shot and different intensities were selected for each tested material: Steel shot ASH110, ceramic shot Z150 and a combination of both ASH110 and Z150 for double peening.

Table 2: Shot peening parameters for AlSi10Mg, MS1 and Ti6-Al4-V samples

No. Pieces	Abrasive	Coverage	Intensity	Intensity	Intensity
			Al Si10Mg	MS1	Ti6-Al4-V
5	**ASH110**	100%	4-7A	6-10A	6-10A
5	**Z150**	100%	4-7A	4-7A	4-7A
5	**ASH110 + Z150**	100 + 100%	4-7A	6-10A + 4-7A	6-10A + 4-7A

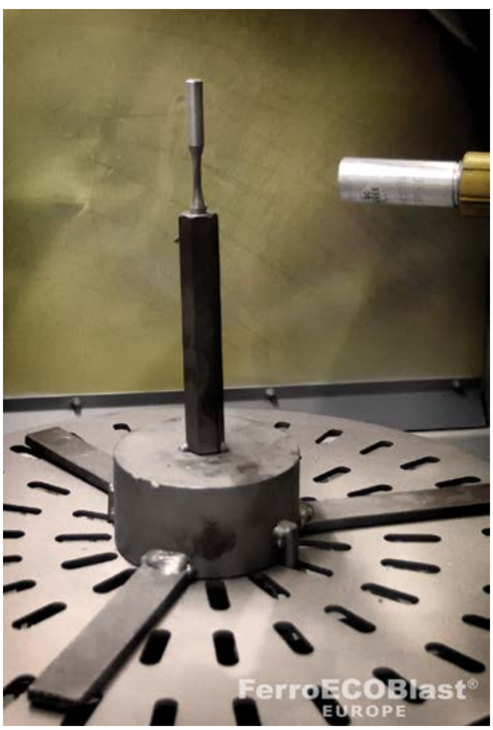


Figure 2: Shot peening of samples in the machine

FATIGUE STRENGTH TESTING

Tests for fatigue strength were performed in the laboratory with a dedicated machine on five samples that had not been treated with shot peening. The goal was to determine the load required to reach the breaking point of the test piece in 10^5 cycles and at a frequency of approximately 70 Hz. After determining the parameters, we tested five more reference pieces with the same parameters which again were not treated with shot peening, and five more pieces for each individual material and each type of shot peening separately for a total of 60 tests.

RESULTS OF FATIGUE STRENGTH TESTING

As shown in the diagrams below, shot peening had a very positive effect on the lasting dynamic strength of the tested pieces. A reference piece, not treated with shot peening, reached breaking point in an average of 10^5 cycles, while pieces treated with shot peening survived from an average of 5×10^5, and up to 2×10^6 cycles. The number of cycles required for failure depends on the shot peening parameters as well as on the base material of the tested piece.

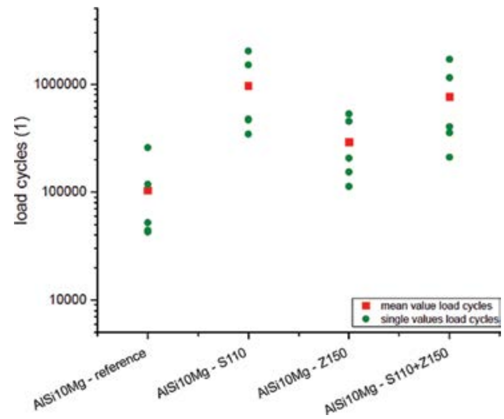


Figure 3. Diagram of tests on AlSi10Mg samples

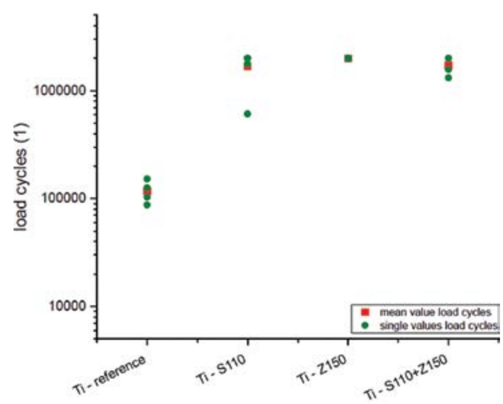


Figure 4: Diagram of tests on Ti6-Al4V samples

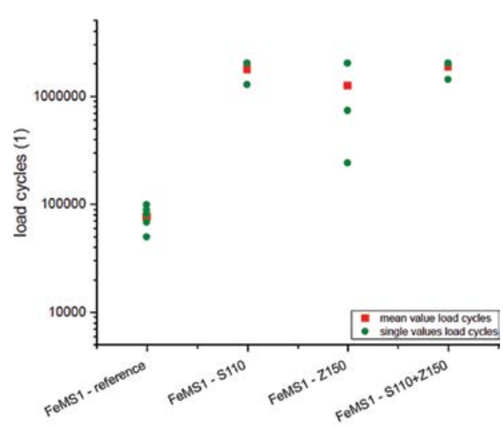
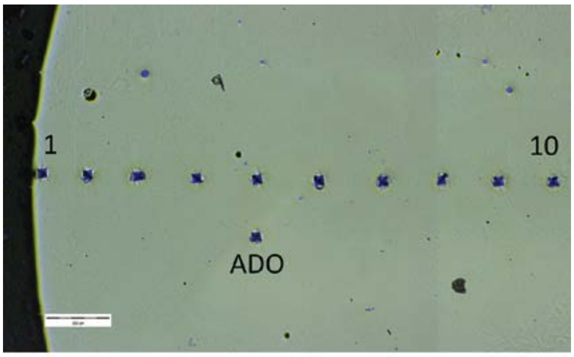


Figure 5: Diagram of tests on MS1 samples

METALLURGICAL ANALYSIS

The purpose of the metallurgical analysis was to check the effect of shot peening on the base material of the tested samples, the result of which is best reflected in the microhardness. Measurements were performed on the same kind of samples tested for sustained dynamic strength.



$$\Delta^{XY} > 30 \cdot h_{max} = 30 \cdot 4.7 = 141\ \mu m$$

Figure 6: Image of microhardness measurement of samples

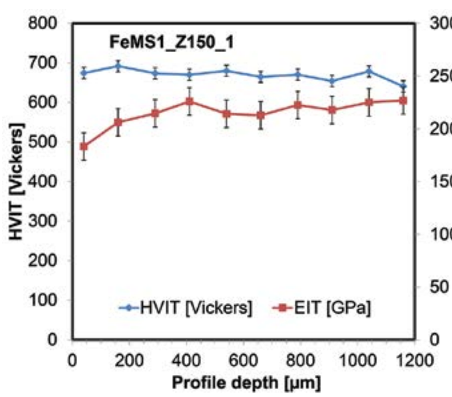


Figure 7: Example of a graph of HV microhardness measurement and modulus of elasticity of a sample of MS1

SUMMARY

The results of the research confirmed a significant positive effect of shot peening on the fatigue strength of parts produced by AM, regardless of the base material.

The greatest effect was detected on the titanium alloy Ti6-Al4V where the lifetime was extended up to 20 times. It could have been even better, but we stopped testing at 2 × 10^6 cycles. Samples made of MS1 steel showed a lifetime extension of approximately 15 times, and finally samples made of AlSi10Mg, where the improvement was up to 8-10 times.

The results show the best outcome is obtained with shot peening using steel shot S110, followed by double peening with steel and ceramic shot S110 + Z150 and concluding with ceramic shot Z150. Results for pieces made of AlSi10Mg presented the largest deviation, followed by the steel samples, while with Ti6-Al4V all tested methods of shot peening produced very good results.

The effects of shot peening on the microhardness of the material, as the metallurgical analysis has shown, were not significant. Only a slight increase of microhardness has been detected on the surface and up to 200-300 µm in depth. The best effect was detected with double peening with S110 + Z150, which displayed an increase of the modulus of elasticity.

Shot peening significantly improves the mechanical properties, fatigue strength and corrosion resistance of products produced with AM processes thus extending their lifetime.

Therefore, the manufacturer is able to optimize the designs of such products, reducing their weight, which in the end means a faster and more cost-effective production process and significant energy savings during operation.

As shown in this study, keeping shot peening in mind from the design phase makes a lot of sense for all metal parts produced by additive manufacturing methods.

Figure 8: One of FerroECOBlast®'s many automatic shot peening machines