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IMPROVEMENT OF THE FATIGUE BEHAVIOUR OF ADDITIVE MANUFATURED SCALMALLOY BY USING SURFACE IMPROVEMENT PROCESSES

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Abstract
The use of light metals such as Aluminum alloys has experienced a remarkable increase for the additive manufacturing (AM) industry, especially in aerospace.
AM Scalmalloy®. (an Al-Mg-Sc alloy) shows outstanding behavior with much higher mechanical performance with respect to other alloys for powder bed fusion laser-based (PBF-LB) process like AlSi10Mg or AlSi7Mg. Recent studies have mainly focused on static loading, with minor attention to cyclic loading despite its vital importance in many applications.
In this work, the fatigue performance of PBF-LB Scalmalloy was investigated considering the effects of surface treatments to identify the set of optimal post-processes. Shot peening with steel and glass shots, laser peening combined with C.A.S.E. (Chemically Assisted Surface Enhancement) treatments were initially selected. *Blind hole drilling* method has been applied to obtain depth residual stress profiles. Tensile and fatigue tests were also performed for each surface treatment.
Steel Shot Peening + C.A.S.E. lead to significantly improvement in the fatigue life of the Al-Mg-Sc parts, reducing internal defects and roughness, thanks to the generation of a favorable residual stress field. Afterwards, the treatments were validated in an optimized AM demonstrator.

Keywords Scalmalloy, fatigue, roughness, additive manufacturing

Introduction
The main aim of the study is to evaluate the effect of different surface treatments on fatigue behavior of components made of Scalmalloy by means of PBF-LB additive manufacturing technology.

It is widely known that roughness and internal defects represent the two principal issues of additive manufactured components. The combination of them leads to poor fatigue performance, and this is the reason why post-processing plays such a relevant role.

Curtiss Wright Surface Technologies, Metal Improvement Company LLC, thanks to its more than 6 decades of experience applying treatments to improve fatigue life, is in the best position to prescribe the right set parameters to mitigate the aforementioned issues.

In this job, the following specimens were manufactured:

- 60 specimens for fatigue tests
- 21 specimens for tensile tests
- 10 specimens for residual stress measurements
- 10 auxiliary samples (5 for density control and 5 for metallographic inspection)

Over all the samples, in order to improve the performance, a heat treatment plus abrasive blasting was applied. The heat treatment consisted of 325ºC over four hours with a slow cooling down afterwards.

The batches to be tested are described as follows:

Group 1: Reference (Only annealed and abrasive blasted). Name of group: **SB**
Group 2: Steel Shot Peening. Shot: 170R / 8-10A / 500% coverage. Name of group: **SP1**
Group 3: Glass Bead Peening: Shot AGB 35 / 16-20N / 200% coverage. Name of group: **SP2**
Group 4: Steel Shot Peening + C.A.S.E. (the criteria was that the residual stress profile was better with steel shot peening, as it will be shown later). Name of group: **SP1+C.A.S.E.**
Group 5: Laser Peening: 3.2mm laser diameter / 50% / 6 pulses. Name of group: **LP1**
Group 6: Laser Peening: 2.5 mm laser diameter / 50%/ 6 pulses. Name of group: **LP2**
Group 7: Laser Peening + C.A.S.E. Name of group: **LP1+C.A.S.E.**

Experimental Procedures
For this study, the following tests have been carried out:

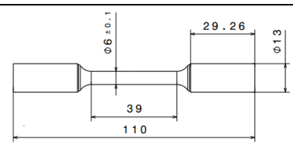
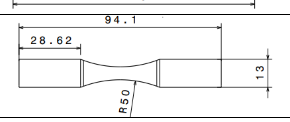
Type of test	Test	Type of Specimen	Quantity of types	Quantity of specimens/type	Spec.
NDT	XCT	-	2 samples of each batch after treatment		
NDT	Roughness measurement	-	All the samples		ISO 4287
DT	RS measurement	Flat specimens (10x20x100mm)	7 (SB/SP1/SP2/SP1+C.A.S.E./ LP1/LP2/LP1+C.A.S.E)	1 (7 samples in total)	
DT	Tensile test		7 (SB/SP1/SP2/SP1+C.A.S.E./ LP1/LP2/LP1+C.A.S.E)		ASTM E8M-04
DT	Fatigue test		3 (SB / SP1 / SP1+C.A.S.E.)		ASTM E466
Others	Fractography	Broken fatigue samples	3 (SB / SP1 / SP1+C.A.S.E.)	1 (3 in total)	
Others	Edge analsyis	Samples from RS measurement	7 (SB/SP1/SP2/SP1+C.A.S.E./ LP1/LP2/LP1+C.A.S.E)	1 (7 in total)	
Others	Metalography	Samples from RS measurement	7 (SB/SP1/SP2/SP1+C.A.S.E./ LP1/LP2/LP1+C.A.S.E)	1 (7 in total)	

Table 1: List of tests

Results

Hereinafter, the most relevant results of each type of test will be shown. In terms of roughness, the samples where the residual stress was going to be measured, were used to measure the roughness as well. For that, a PCE-RT2300 was used, taking 5 values from each specimen.

Group	R_a after SB average	σ [µm]	R_a after SP/LP [µm] average	σ [µm]
SB	3,09	0,28	-	-
SP1	5,04	0,21	4,54	0,44
SP2	3,87	0,56	4,58	0,39
SP1+C.A.S.E	3,70	0,45	3,74	0,02
LP1	5,45	0,60	5,28	0,48
LP2	4,32	0,27	6,66	0,85
LP1+C.A.S.E	4,19	0,50	3,84	0,41

Table 2: Roughness values

As we can observe, the Shot Peening and Laser Peening treatments increase the roughness values, so they introduce a detrimental effect in terms of fatigue life, which will be analyzed later. However, the C.A.S.E treatment minimize such effect, providing a softer surface without detrimental of the compressive residual stress. This will contribute to better fatigue performance, specially against HCF and VHCF (Very High Cycle Fatigue) scenarios.

In regards to Residual Stress measurement, blind hole technique was applied. For that, MTS3000 (Sint Technology) equipment was used. The following results were obtained:

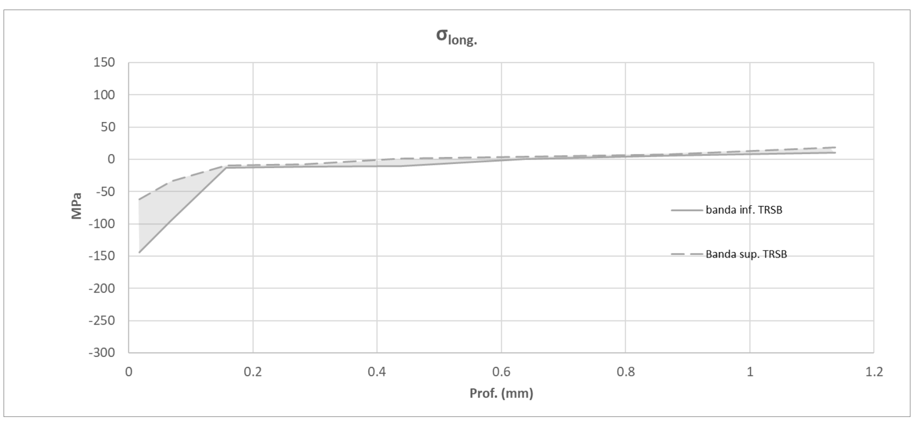


Figure 1: Residual stress in longitudinal direction for SB group

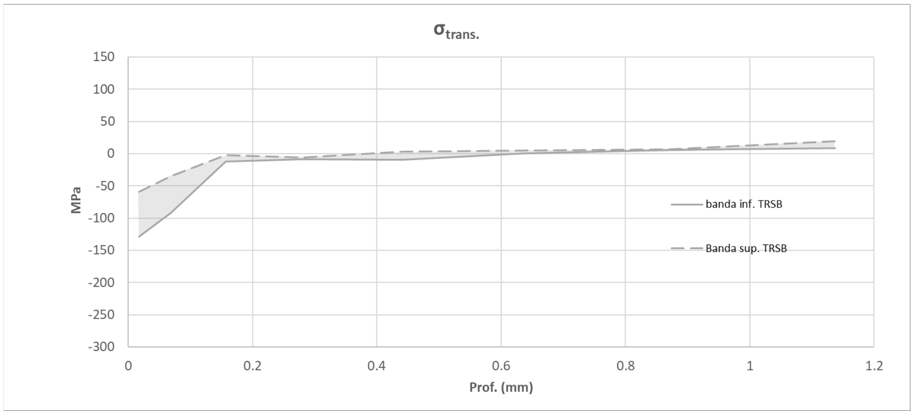


Figure 2: Residual stress in transversal direction for SB group

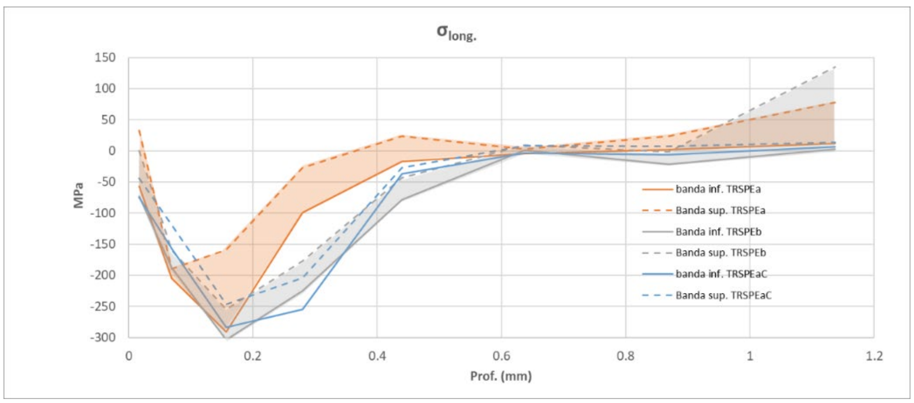


Figure 3: Residual stress in longitudinal direction for SP1, SP2 and SP1+C.A.S.E. groups

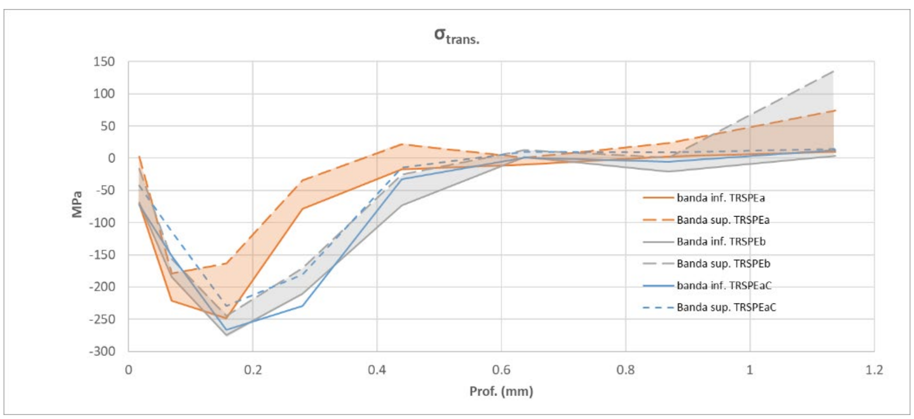


Figure 4: Residual stress in transversal direction for SP1, SP2 and SP1+C.A.S.E. groups

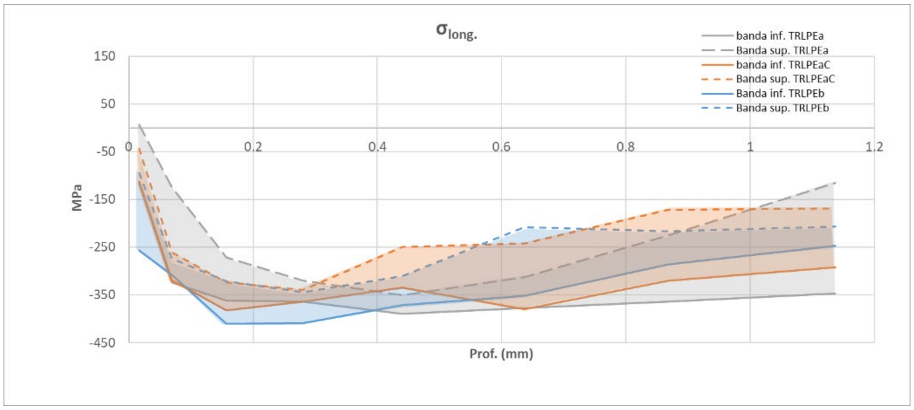


Figure 5: Residual stress in longitudinal direction for LP1, SLP2 and LP1+C.A.S.E. groups

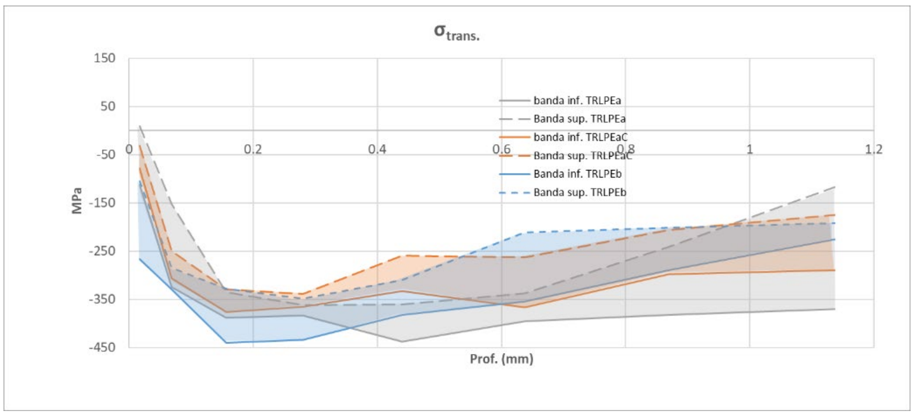


Figure 6: Residual stress in transversal direction for LP1, LP2 and LP1+C.A.S.E. groups

At this stage, there are just a couple of facts to be highlighted. First, the batches where Laser Peening was applied show deeper profile, although similar compressive values. This is crucial for those applications where we could find LCF (Low Cycle Fatigue) issues, as well as those where internal defects can be found. On the other hand, we can observe that C.A.S.E. does not almost make any impact in terms of residual stress. That means that it represents a nice complement to maintain compression level and, in parallel, improve the surface condition.

Once the residual stresses had been measured, the tensile and fatigue tests were carried out. As follows, tensile strength test results are shown:

GROUP	Young Module E (GPa)	σ E [GPa]	UTS R_m [Mpa]	σ R_m [MPa]	Yield Strength $R_{p0,2}$ [Mpa]	σ $R_{0,2}$ [MPa]	Elongation (%)	σ def [%]
SB	68,58	0,36	507,90	2,98	485,70	3,41	10,48	0,010
SP2	69,42	1,08	509,70	3,51	479,33	5,15	9,28	0,014
SP1	68,79	0,17	512,24	1,80	476,40	1,65	10,05	0,020
SP1+CASE	70,34	0,95	515,56	2,30	480,73	5,10	7,67	0,017
LP1	68,17	1.37	506,33	4,38	473,7	2,44	8,88	0,013
LP2	69,99	0,91	509,45	1,90	480,5	5,81	10,88	0,021
LP1 + CASE	70,41	0,63	515,63	5,27	482,4	1,69	9,64	0,011

Table 3: Tensile strength values

As we could have anticipated, there is no major changes against tensile static solicitation with or without Peening treatments.

Now we come to the question of fatigue behaviour, which is expected to be the one where Peening treatment make the most meaningful impact.

Specimen	σ_{max}**[MPa]**	f **[Hz]**	**Cycles**	**Kind of failure**
SB-1	320	111,80	21000	Superficial
SB-2	290	111,78	24500	Mixta
SB-3	260	111,39	44700	Interior
SB-4	220	112,28	663000	Interior
SB-5	190	112,25	5000000	*run out*
SB-6	320	111,68	2,87E+04	superficial
SB-7	290	112,09	6,34E+04	Interior
SB-9	260	111,90	5,57E+04	-
SB-10	220	111,46	1,40E+05	Interior
SB-11	190	111,72	5000000	*run out*
SP1-1	290	111,80	598300	Interior
SP1-2	220	111,78	5000000	*Run-out*
SP1-3	320	111,39	151100	Superficial
SP1-4	320	112,28	108000	Mixta
SP1-5	290	112,25	195800	Superficial
SP1-6	220	111,68	1844100	Interior
SP1-7	260	112,09	1116000	Interior
SP1-9	260	111,90	301700	Interior
SP1-10	260	111,46	321600	Mixta
SP1-11	290	111,72	156500	Mixta
SP1+C.A.S.E-1	290	111,44	923400	Interior
SP1+C.A.S.E-2	220	112,22	5000000	Run-out
SP1+C.A.S.E-3	320	111,52	130600	Superficial
SP1+C.A.S.E-4	320	111,63	105500	Superficial
SP1+C.A.S.E-5	290	111,58	497100	Mixta
SP1+C.A.S.E-6	220	111,94	4906600	Interior
SP1+C.A.S.E-7	260	111,49	1741100	Mixta
SP1+C.A.S.E-9	260	111,63	1384400	Interior
SP1+C.A.S.E-10	260	111,00	269300	Interior
SP1+C.A.S.E-11	290	111,25	151500	Superficial

Table 4: Fatigue tests results

In addition, Wöler curves are shown as well:

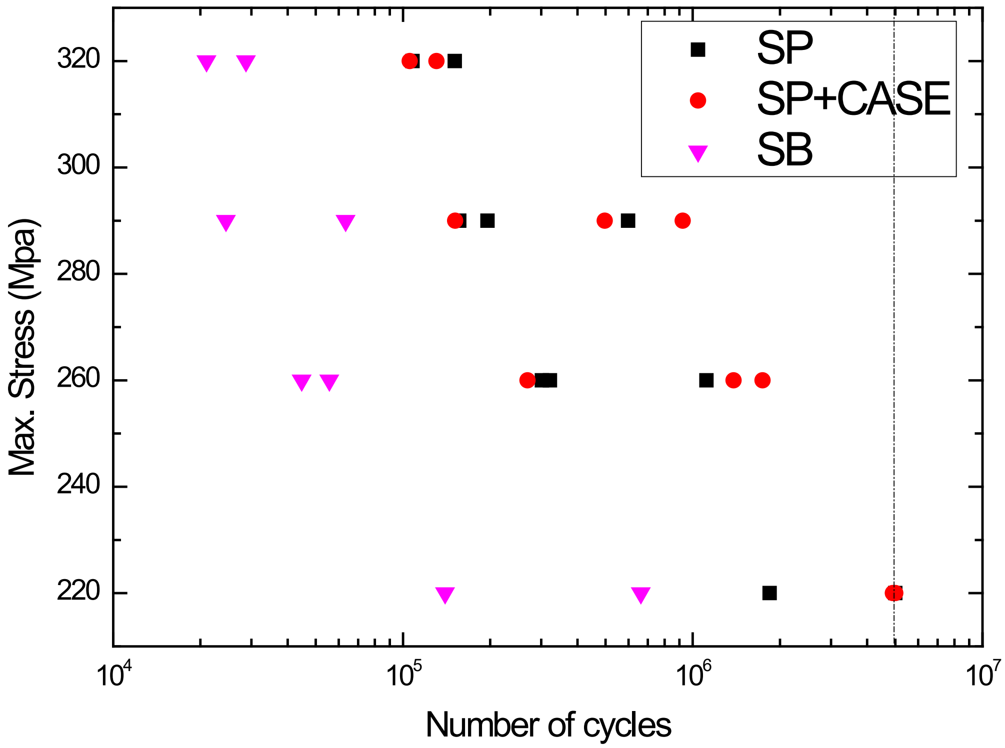


Figure 7: S-N curves for SB, SP1 and SP1+C.A.S.E. groups

Discussion and Conclusions

According to the obtained results, we can state that both, Shot Peening and Laser Peening, and specially combined with C.A.S.E. process, improve the fatigue behavior of components made of Scalmalloy manufactured by additive manufacturing.

Depending on what kind of fatigue issue we are in front of, the parameters of the Peening treatment has to be carefully defined. Several tips to take into account:

If main problem is HCF (High Cycle Fatigue) or VHCF (Very High Cycle Fatigue), it is of utmost importance to consider that the better the surface is, the better the performance will be. So, C.A.S.E. process will be good complement for either, Shot Peening or Laser Peening.

In contrast, if we face a LCF (Low Cycle Fatigue) issue, highly likely a deeper compressive residual stress profile will contribute to improve the performance, rather than surface condition. In those cases, Laser Peening will provide better results.

On top of that, for this study, the treatment called SP1+C.A.S.E. was also applied over a demonstrator, which had previously been optimized by CATEC. The aim was to reinforce the conclusions not only with specimens, but also with a real part. It is appreciated that the life of the component is extended up to additional 60%.

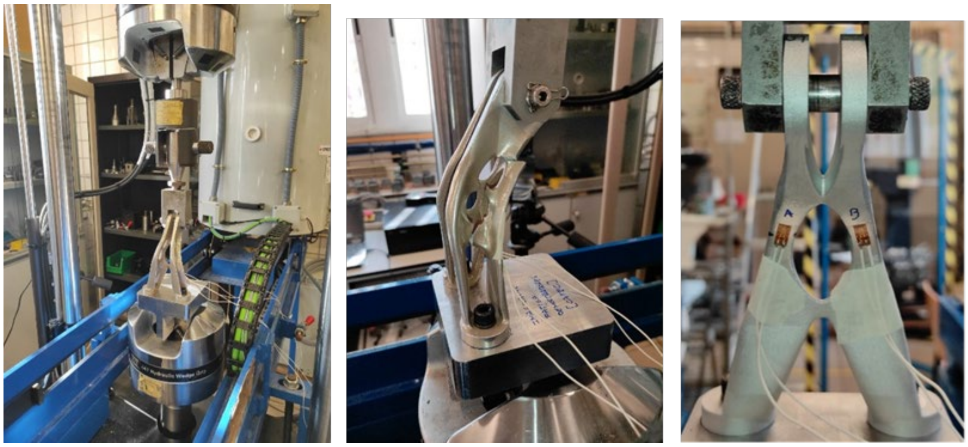


Image 1: Different views of the demonstrator being tested

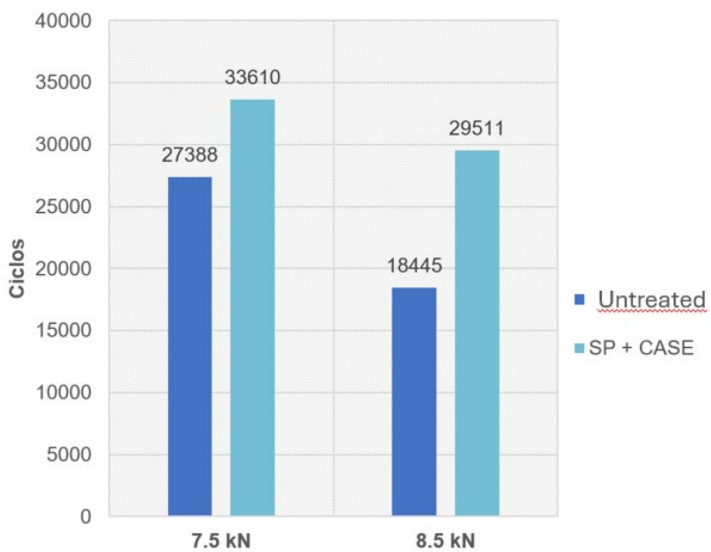


Figure 8: Demonstrator fatigue life at two different load levels, with and without SP+C.A.S.E. treatment

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