MICROSTRUCTURE AND MECHANICAL PROPERTIES OF MARAGING STEEL 300 AFTER SELECTIVE LASER MELTING

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Reviewed, accepted September 23, 2010

Abstract

Selective laser melting (SLM) is an additive manufacturing process for the direct fabrication of prototypes, tools and functional parts. The process uses a high intensity laser beam to selectively fuse fine metal powder particles together in a layer-wise manner by scanning cross-sections generated from a three-dimensional CAD model. The SLM process is capable of producing near fully dense functional products without almost any geometrical limitation and having mechanical properties comparable to those produced by conventional manufacturing techniques. There is a wide range of materials that are suitable to be processed by SLM including various steels, Ti, Al and CoCr alloys. Being one of these materials, maraging steel 300 (18Ni-300) is an iron-nickel steel alloy which is often used in applications where high fracture toughness and strength are required or where dimensional changes have to remain at a minimal level, e.g. aircraft and aerospace industries for rocket motor castings and landing gear or tooling applications. To achieve its superior strength and hardness, maraging steel, of which the name is derived from 'martensite aging', should be treated with an aging heat treatment. In this study, the effect of the SLM parameters (scan speed and layer thickness) on the obtained density, surface quality and hardness of maraging steel 300 parts is investigated. Moreover, various aging heat treatments (different combinations of duration and maximum temperature) are applied on the SLM parts to achieve high hardness values. The mechanical testing of maraging steel 300 specimens produced by SLM and treated with an appropriate aging treatment is accomplished by impact toughness and tensile tests and compared to the results obtained using conventional production techniques. Additionally, the microstructures of as-built and heat treated parts are investigated.

Introduction

Maraging steels are well known for their high strength, high fracture toughness, good weldability and dimensional stability during aging. Due to this unique combination of several attractive features, maraging steels find extensive use in high performance industrial and engineering parts such as aerospace and motor racing applications. Some of the applications can be listed as rocket motor castings, drill chucks, tools for punching, extrusion, plastics injection moulds and metal casting dies [1]. Maraging steels offer an attractive alternative to the medium to high carbon tool steels since they do not suffer some problems like high carbon content promoting corrosion and quench cracking which may only become evident during service and result in unexpected failure. The low carbon content of maraging steels reduces the risk for quench cracking, while the high nickel content and absence of carbides provides a good corrosion resistance [2].

Selective Laser Melting (SLM) is a promising technology due to almost unlimited geometrical freedom especially for tooling applications. It is possible to produce complex geometries with internal cavities by SLM such as conformal cooling channels. Conformal cooling channels are generally considered to be almost impossible to be built by conventional machining techniques but allow major reduction in injection moulding cycle time [2]. Therefore, SLM of maraging steels can offer new opportunities in tooling applications by producing parts with almost full density and high freedom in geometrical complexity. In this study, SLM of maraging steel 300 is taken under investigation regarding many aspects.

In the scope of this study, the change of part density and surface quality was determined while varying the SLM process parameters (scan speed, layer thickness) from the recommended values by the SLM machine vendor. Micro and macro hardness measurements were conducted on the produced specimens to test the effect of those parameters on hardness of as-built parts. Since maraging steels obtain their superior mechanical properties, i.e. high strength and toughness, after an aging heat treatment, different aging conditions were tested to find the relationship between aging conditions (duration and maximum re-heating temperature) and obtained hardness. Before testing this material mechanically (by tensile and Charpy impact testing), the influence of laser re-melting after every layer is studied to reduce the porosity formed during SLM.

Experimentation

During the experiments, maraging steel 300 from Concept Laser GmbH (commercially named as CL50WS) was used. The test specimens were built from gas atomized powder of specification and size fraction listed in Table 1. Figure 1 provides typical morphology of the tested powders before processing showing that the majority of powder particles bear spherical and near-spherical morphology. This morphology without sharp edges and corners ensures free flow of the powder during layer deposition thereby increasing process efficiency [3].

Table 1: Specification and size ranges of gas atomized maraging steel powder

Material	*DIN No.*	*Material name*	*Size ranges (µm)*	*d_{50} (µm)*	*bulk density (g/cm^3)*
CL50WS	1.2709	X3NiCoMoTi 18-9-5	25-63	43.7	8.1

Table 2: Experimental processing parameters

Material	*Scan speed (mm/s)*	*Scan spacing (µm)*	*Layer thickness (µm)*
CL50WS	120-600	125 (a_1 = 70% of the spot size $\phi_{99\%}$)	30, 40, 50, 60

CL50WS powder was processed on a Concept Laser M3 Linear SLM machine [4] which is equipped with a 100 W Nd:YAG laser and has a laser beam diameter ($\phi_{99\%}$) of about 180 µm at the powder bed surface. Experiments were carried out using the maximum available laser power (~105 W). A wide range of scan speed at various layer thicknesses was examined as given in Table 2. In order to minimize the effect of thermal gradients and thermal induced stresses in the component, island scanning (a patented scan pattern from Concept Laser) was used [5]. In this scanning strategy, part surface at each slice is divided to small square islands of 5 mm × 5 mm. The islands are scanned in a random way while scanning direction is altering a right angle with respect to the neighboring islands.

The surface roughness of the as-processed samples was measured on horizontal top surfaces using a contact surface profilometer, Talysurf 120L from Taylor Hobson Ltd. Density was measured according to the Archimedes' method by weighing the samples in air and subsequently in ethanol. The Archimedes' method is a simple and fast method to evaluate different processing conditions. However, it is not very suitable to compare the densities of SLM parts having very close results due to pores being sometimes filled with un-melted powder particles. A coating with lacquer was also applied to avoid ethanol absorption in open pores at lower densities (<90%). Density results are presented as the arithmetic means of three measurements at each processing condition and are expressed as relative density by taking materials' bulk density as 8.1 g/cm^3 (See Table 1).

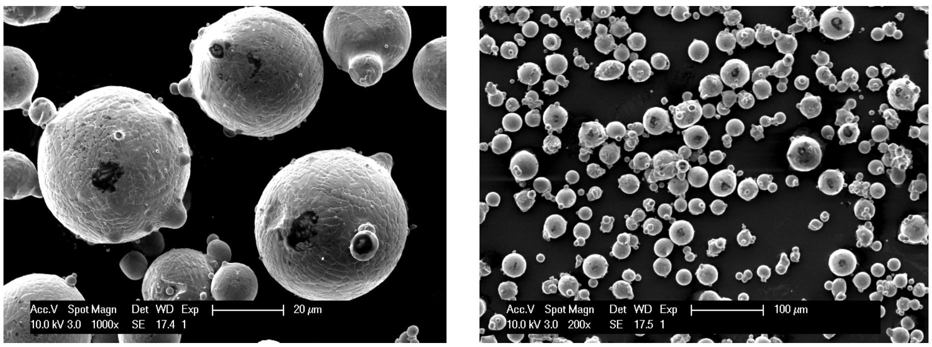

Figure 1 : SEM micrographs of CL50WS powder from Concept Laser

Experimental Results and Discussion

Relative Density

Figure 2 shows the relative density obtained for different scan speed and layer thickness values. The recommended parameters for CL50WS powder by the machine vendor are a scan speed of 200 mm/s, scan spacing of 125 µm and 30 µm layer thickness (See Figure 2). The results showed that the relative density reduces with increasing speed even though its decline is less obvious at lower speed ranges for all layer thicknesses. The observed trend is logical since the delivered energy density decreases with increasing scan speed. Results indicate that an increase of layer thickness from 30 to 40 µm for instance, at a constant scan speed, has little deteriorating effect on the density as long as the scan speed is equal or less than the "recommended" speed. Such an increase in layer thickness corresponds to 25% lower scanning time as well as 25% reduction on layer deposition time for this material without any significant reduction in the density [6].

The maximum density obtained with maraging steel 300 on the Concept Laser M3 with an Nd:YAG laser is about 99% of the material's bulk theoretical density, showing promising capabilities for many application areas. The results of an experimental study about SLM of maraging steel 300 on an EOSINT M270 equipped with a fiber laser showed that there is a reduction in the obtained density at low scan speeds (lower than recommended scan speed which is 750 mm/s for that case) [6], a phenomenon not observed on the Concept Laser machine with Nd:YAG laser. The reason for the reduction in the density for EOS M270 machine was found to be the bad surface quality due to severe balling, preventing the coater to perform a uniform layer deposition at very low scan speeds [6].

Surface quality

In order to investigate the influence of building rate on the parts' surface quality, the surface roughness R_a has been measured on horizontal top surfaces of parts produced with different scan speeds and layer thicknesses. R_a values are measured without using any cut-off filter. Figure 3 depicts the average value and 95% confidence interval of R_a measurements (3 samples built per setting and 10 R_a measurements on each sample).

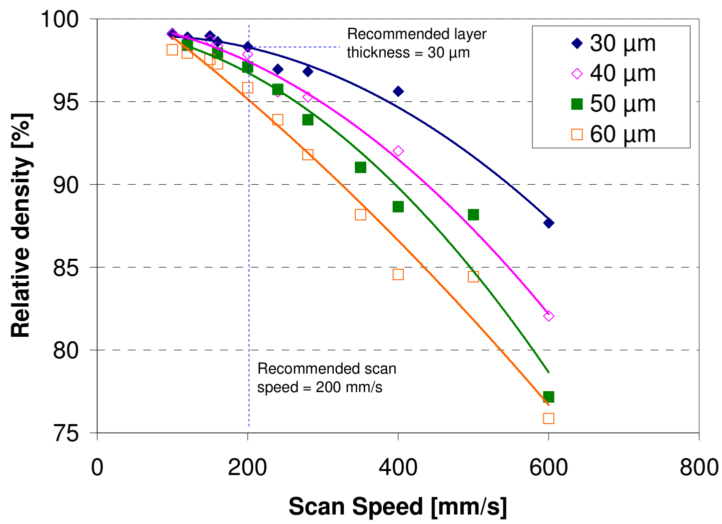

Figure 2 : Relative density versus scan speed for CL50WS for different layer thickness values

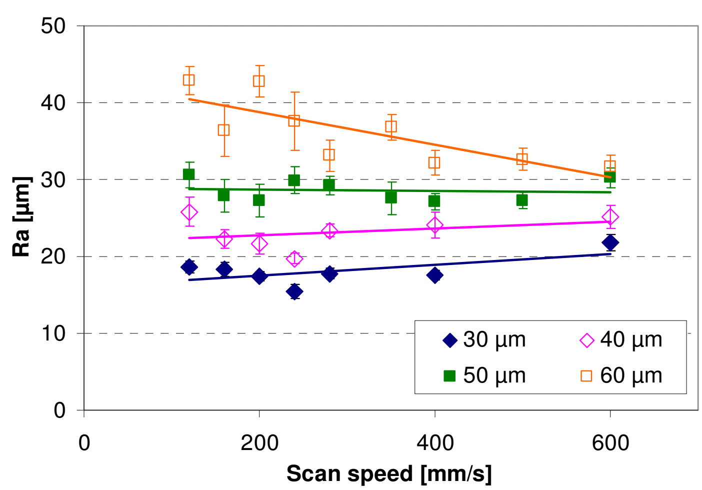

Figure 3 : R_a measured on top surfaces versus scan speed for CL50WS for different layer thicknesses with 95% confidence intervals

In the tested scan speed range, the roughness R_a is almost independent of the selected scan speed at low layer thickness values. For the highest layer thickness, i.e. 60 µm, the relation between the scan speed and the surface quality seems to be inversely proportional. However, the high variations obtained at low scan speeds with this layer thickness make it difficult to draw concrete conclusions.

Macro and micro hardness measurements

In order to investigate the effect of the process parameters on hardness, macro and micro scale hardness measurements were conducted on the side cross-sections of specimens produced with different settings of scan speed and layer thickness (see Figure 6 for the definition of side cross-section). The macro hardness measurements were employed to get an idea of overall hardness of the samples taking porosity into account whereas the micro hardness tests were used to find out the direct influence of different process parameters on the material hardness. The macro hardness results were obtained with Rockwell A tests by measuring the depth of penetration of an indentation under a specified load (60 kg) compared to the penetration made by a preload (10 kg). The results are presented in Figure 4 showing that the hardness is significantly affected by the density. At low scan speed, i.e. range close to the recommended speed (200 mm/s) where the obtained densities are high and almost independent from the layer thickness, there is but a very slight change in the measured hardness. As the scan speed is increased, the hardness values are significantly reduced due to increased porosity.

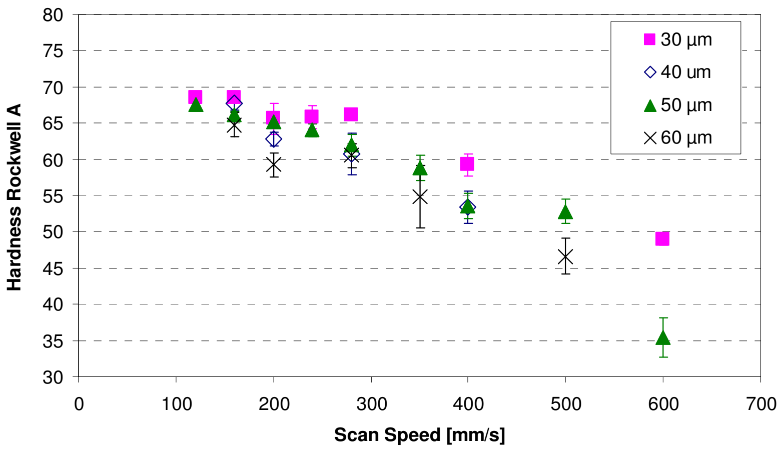

Figure 4 : Average macro hardness measured on cross-sections versus scan speed for different layer thicknesses with 95% confidence intervals

The results for micro hardness measurements, which were conducted with Vickers hardness measurement device with a test load of 0.5 kg and a pyramidal diamond indenter, are depicted in Figure 5 for two different layer thickness values. It should be noted that the measurements were only taken on samples which were dense enough to take measurements with proper spacing between indentations and pores. It was difficult to find solid regions to take reliable measurements as suggested by the ASTM standard for the parts produced at high scan speeds and layer thickness values. At low scan speed range, the change of the scan speed or layer thickness does not significantly alter the micro hardness as depicted in Figure 5. Since the process parameters don't significantly influence the micro hardness, it may be concluded that their influence on the macro hardness is only due to their influence on the density.

Microstructural investigation

The microstructural investigation of the samples is accomplished by preparing the samples' cross-sections in two directions. One cross-section is taken along the building axis (cs1–side) whereas the other has a normal parallel to the building axis (cs2-top) (see Figure 6). The cross-sections are observed with optical microscopy and scanning electron microscopy (SEM). To reveal the microstructure, a mixture of 15 ml H_2O, 15 ml acetic acid, 60 ml HCl and 10 ml HNO_3

was used to etch the samples. A micrograph taken on a cross-section (cs2) of a part built with a layer thickness of 60 µm and a scan speed of 120 mm/s is shown in Figure 7a. Figure 7a clearly depicts the bi-directional scan tracks (see arrows) and pores (black spots in the figure). Spherical and irregular pores can be observed. It is also observed that most of the irregular pores are present on the connection of scan tracks, meaning that a scan spacing factor (a_1) of 70%, recommended by machine vendor, is too high. The spacing factor should be decreased in order to have a better track overlap and less porosity.

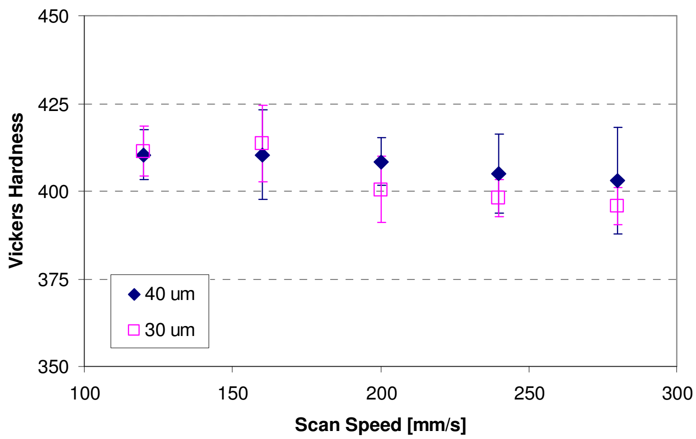

Figure 5 : Average micro hardness measured on cross-sections versus scan speed for different layer thicknesses with a 95% confidence level

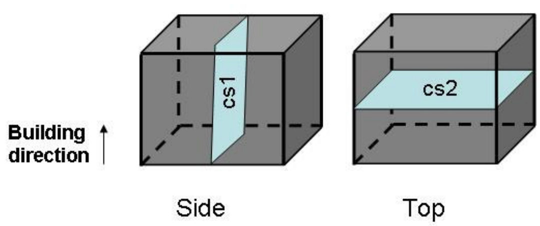

Figure 6 : Illustration of side and top cross-sections with respect to the building axis

The side cross-section (cs1) of a part produced with a layer thickness of 30 µm and a scan speed of 150 mm/s is depicted in Figure 7b. After etching, the cross-sections of the scan tracks become clearly visible. If the scanning direction is perpendicular to the section, then the cross-section of a scan track appears as a curved line. These curved melt pool lines formed during the last layer of the part can be used to calculate the depth of the melt pool which is about 80-90 µm for the case depicted in Figure 7b. Not only the melt pool lines of overlapping scan tracks are visible, but also the cross-sections of longitudinal scan tracks that result from the fact that the orientation of the scan vectors are rotated 90° from layer to layer (i.e. alter from parallel to perpendicular to the cross-section).

The cross-sections were observed under a SEM at high magnifications. The SEM micrographs taken on two cross-sections (cs2 and cs1, respectively) are depicted in Figure 8. The micrograph (cs2) on the left shows again bi-directional scan tracks while the one on the right (cs1) depicts cellular/dendritic morphology and epitaxial growth. In SLM, the cooling rate is very high and rapid solidification prevents formation of a lath martensite. Intercellular spacing is less than 1 µm and this contributes to the excellent strength and hardness. These statements are also validated by other researchers working on direct metal laser sintering of maraging steel 300 processed on an EOS machine [2]. One could observe some large inclusions with a size of about 10-20 µm, visible in the two cross-sections in Figure 8a and b as dark spots. The EDX analysis carried out on these samples confirmed that these were titanium and aluminum combined oxides (TiO_2:Al_2O_3). Those inclusions deteriorate the mechanical properties of components, especially at aged conditions where the maraging steel is more brittle than as-built condition [2].

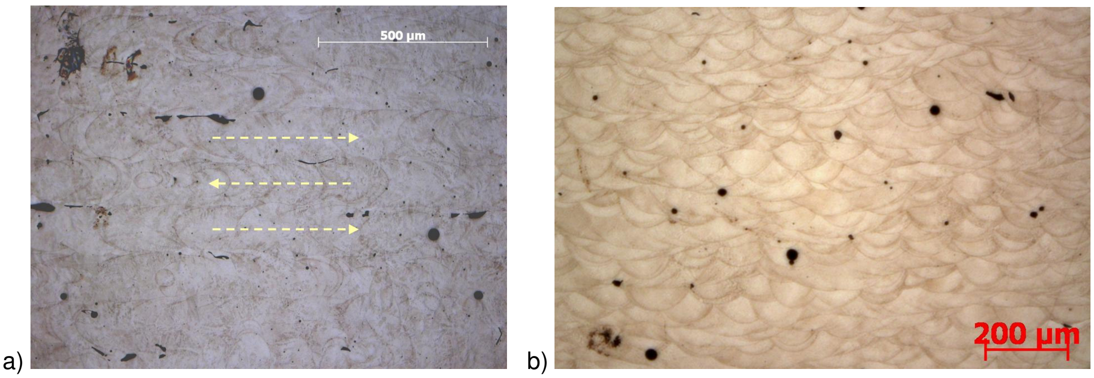

Figure 7 : Micrographs after etching of cross-sections a) top-cs2 b) side-cs1 of a sample after etching

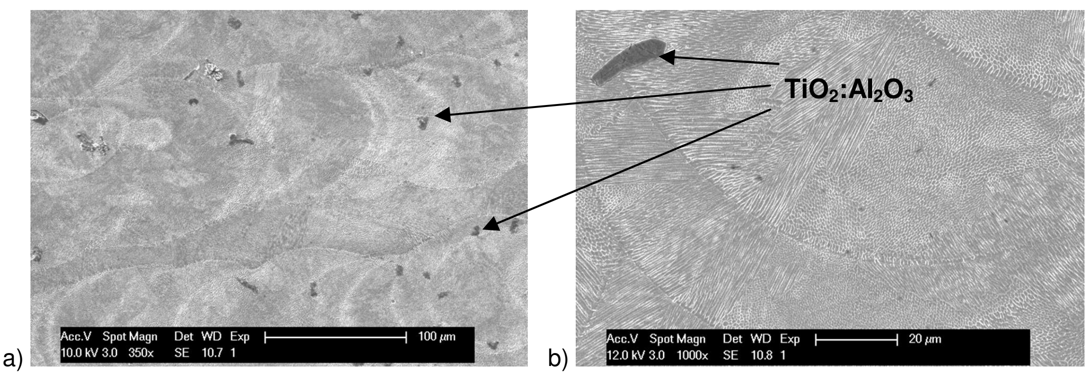

Figure 8 : SEM pictures of the cross-sections (cs2-top and cs2-side) of a sample

Effect of re-melting

In order to decrease the porosity in SLM parts, laser re-melting may be an easy solution which can be applied during the SLM process by re-melting each layer a second time before depositing a new layer of powder. This will increase the production time, but may not be very important for some applications which cannot tolerate 1-2% porosity. Many mechanical and thermal properties, e.g. fatigue resistance, yield strength, corrosion resistance, ductility, thermal conductivity, etc. highly depend on the part density. Therefore, the effect of re-melting on density, hardness and microstructure is investigated.

Before testing the effect of laser re-melting, the scan spacing factors that are utilized on the Concept Laser M3 Linear machine were optimized for a high density without any aligned porosity. A scan spacing factor (a_1) of 62% between scan tracks was found to give sufficient overlapping. The overlapping factors for the islands (a_2 and a_3) were also optimized as 35% and 50%, respectively [7]. These optimized scan spacing factors were utilized for the production of parts to test the influence of laser re-melting.

The SLM and laser re-melting conditions for the samples produced with and without laser re-melting are given in Table 3. For the first three parts, the SLM parameters (a scan speed of 150 mm/s, a layer thickness of 30 µm and a laser power of 105 W) were the same. Part 1 was not treated with laser re-melting for comparison while the other two samples (part 2 and 3) were exposed to laser re-melting with a different scan speed and strategy. The SLM parameters of the last part (part 4) except the scan speed were the same with those of the other parts. The last part was built and re-melted with a scan speed of 200 mm/s. The densities of the four samples were measured by the Archimedes' method and are displayed in Table 3.

Table 3 : Comparison of relative density, micro hardness and scan time for one layer for parts produced with different SLM and laser re-melting parameters

	SLM Parameters	Laser Re-melting Parameters	Relative density (by Archimedes' technique)	Micro hardness (HV)	Scanning time for one layer
Part 1	scan speed = 150 mm/s, laser power = 105 W, layer thickness = 30 µm	no re-melting	99.15%	395.8	t*
Part 2	same as given for part 1	island re-melting (every island is scanned twice in perpendicular directions with the same SLM parameters)	99.41%	412.6	2t*
Part 3	same as given for part 1	long scan vectors scan speed = 100 mm/s, laser power = 105 W, a_1=30% big aperture	99.48%	414.0	4t*
Part 4	scan speed = 200 mm/s, laser power = 105 W, layer thickness = 30 µm	island re-melting	99.25%	390.3	1.5t*

**approximately calculated based on the scan speed and scan spacing factor (a_1) for comparison*

All samples exhibit a very good density above 99% although laser re-molten samples give slightly higher results. However, the density difference between the samples with and without re-melting is more clear when the optical micrographs are observed (see Figure 9). The first row of micrographs shows the top cross-sections (cs2) of three parts where the scan tracks are clearly visible, whereas the second row illustrates the (cs1) side cross-sectional views. As evident from these micrographs, the number of pores present in side or top cross-sections is much higher in the first part whereas the second and third parts possess much higher density compared to the first part albeit having very similar density results by the Archimedes' method.

The micro hardness results, given in the last column of Table 3, are higher than those of maraging steel parts produced with conventional production techniques. In the solution treated condition, the maraging steels presents a soft and deformable martensitic structure with hardness values between 280 and 320 HV [8]. As presented in Table 3, the hardness values obtained from as-built parts after SLM are about 30% higher than those. In the literature, this is attributed to the natural aging which leads to formation of fine precipitates with a size of 20-100 nm during SLM [1].

For mechanical testing, it is very important to achieve almost full density without any aligned or irregular porosity. The density achieved by SLM without any laser re-melting is quite high, i.e. >99%. However, higher densities are still obtained after laser re-melting. Therefore, it was decided to perform mechanical tests on parts produced with settings of part 4 in Table 3, as those settings combine a high density due to laser re-melting and a relatively high production rate due to the re-melting and SLM scan speed of 200 mm/s.

Effect of heat treatment on hardness

The superior properties of the maraging steels, i.e. good strength and toughness, are achieved by the age hardening, or aging, of a ductile, low-carbon body-centered cubic (bcc) martensitic structure with relatively good strength. Therefore, the aging treatment is standard for maraging steels. It is mainly aimed to form a uniform distribution of fine nickel-rich intermetallic precipitates during the aging of the martensite. These precipitates serve to strengthen the martensitic matrix. Secondly, it is aimed to minimize or eliminate the reversion of metastable martensite into austenite and ferrite [9]. In the literature, the hardening of maraging steels during aging has been attributed to two mechanisms, namely the short-range ordering in the cobalt-bearing solid solution and precipitation of nickel-rich intermetallic compounds in the lath martensitic structure [9].

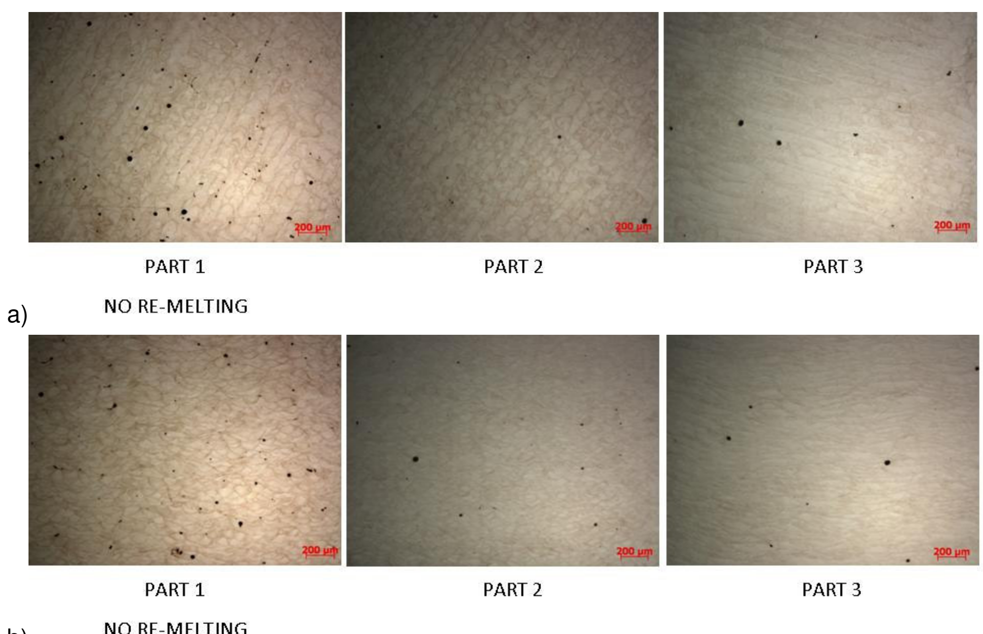

Figure 9 : Micrographs of (a) top cross-section (cs2) (b) side cross-section (cs1)

For maraging steel 300, the recommended values for aging duration and temperature are 3 to 8 hours at a maximum temperature between 460 and 510°C [9]. Therefore, the specimens produced on the Concept Laser M3 Linear machine were heat treated under argon atmosphere with different conditions summarized in Table 4. Resulting hardness values are also given in the same table. Figure 10 shows the same measured micro hardness results in a plot vs. various aging durations at different maximum temperatures. 8 measurements were taken for one sample and the mean of those measurements is given in Table 4 and Figure 10 with 95% confidence intervals. The part aged at 460°C shows a linear relationship between the hardness and the aging time. When one keeps the part longer at this temperature, the hardness continues to increase without any sign of overaging. However for other temperatures tested in the scope of this study, at prolonged durations, the hardness starts to drop slightly. This is an indication of overaging, meaning that the re-heating starts reversion of metastable martensite into austenite, which is an equilibrium phase. Additionally, when a maraging steel is overaged, the coarsening of the intermetallic precipitates takes place. These two phenomena together decrease the hardness as the part is kept at elevated temperatures for a prolonged time. The standard aging heat treatment that is applied after SLM is 3 hours at 480°C which increases the hardness above 634 HV. The tests show that keeping the parts 5 hours at 480°C results in a higher micro hardness close to 650 HV. Although the maximum hardness is achieved with the combination of 8 hours at 460°C, the former heat treatment (5h@480°C) is preferred due to shorter duration. The shrinkage of the samples is also tested and found to be less than 0.7%.

Table 4 : Age hardening conditions

#	*Time (hours)*	*Maximum Temperature (°C)*	*Hardness Results (HV)* Mean ± 95% confidence interval
1	3	460	618.3 ± 8.6
2	3	480	634.8 ± 9.7
3	3	500	645.3 ± 8.2
4	5	460	638.0 ± 9.2
5	5	480	648.4 ± 9.8
6	5	500	642.6 ± 6.7
7	8	460	658.3 ± 9.4
8	8	480	648.0 ± 8.5
9	1	490	596.0 ± 9.1
10	2	490	628.0 ± 6.4
11	3	490	633.0 ± 4.0

Mechanical Testing by Charpy and Tensile Testing

Toughness is an indication of the capacity of a material to absorb energy before failure and is dependent on strength as well as ductility. Notch toughness stands for the capacity of a material to absorb energy in case of a stress concentrator. To test the impact toughness of maraging steel 300, six standard specimens were produced with re-melting (parameters same with part 4 in Table 3). Three of them were heat treated with optimized aging conditions (5h@480°C) and the other three were tested as built. The toughness results, with 95% confidence intervals, are depicted in Figure 11. The impact energy is much lower for the aged parts than as-built. Figure 12 shows the fracture surfaces after Charpy testing at room temperature and reveals that there is almost no lateral expansion with the aged specimen whereas the fracture surface of an as-built part exhibits significant lateral expansion and a ductile fracture. This is mainly due to the formation of fine precipitates during aging which limits the ductile deformation of the specimens.

Charpy impact testing was also carried out in a former study involving different SLM metallic powders [10]. In that study, maraging steel 300 powder from EOS (MS1) was used to make the specimens on an EOSINT M270 machine and the impact energy was found to be 36.3±4.8 J for as-built parts and 10.1±1.4 J for aged parts (3h@480°C). It is not possible to compare the aged parts due to different aging parameters but the impact toughness energies for as-built parts are comparable to the results of the current work. Maraging steel 300 produced by conventional methods however exhibits a higher toughness energy of 27 J for solution annealed and aged condition [11] (see Table 5 for comparison).

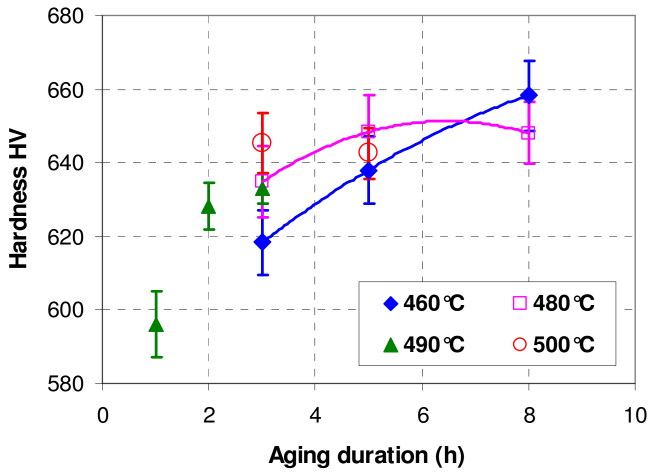

Figure 10 : Effect of various age hardening treatments on hardness with 95% confidence intervals

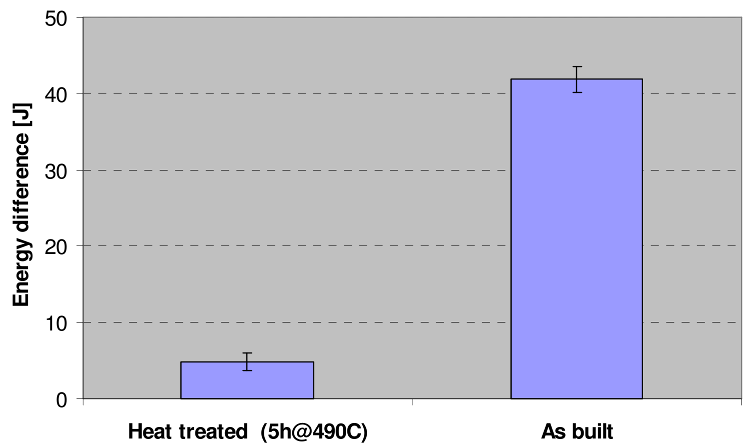

Figure 11 : Effect of age hardening on the toughness energy with 95% confidence intervals

The mechanical properties derived by tensile testing are given in Table 6, together with the values of wrought and solution treated and aged maraging steels [9, 11]. Moreover, the values stated by EOS for this material are included [1]. In our study, four specimens for each condition were tested. Aging led to an increase in hardness and strength through precipitation of intermetallic compounds. The ultimate tensile strength shows an increase of about 70% with aging, whereas the hardness improved by 45%. However, it should be noted that the elongation at break is significantly lowered: from 13.3% to 1.6% after aging (See Figure 13). The comparison of the results to the ones of conventionally produced parts indicates the natural aging phenomenon which occurs due to melting and re-melting of every layer. The cellular microstructure in SLM parts, with an intercellular spacing less than 1 μm, contributes to high strength and hardness that are reached after the SLM process.

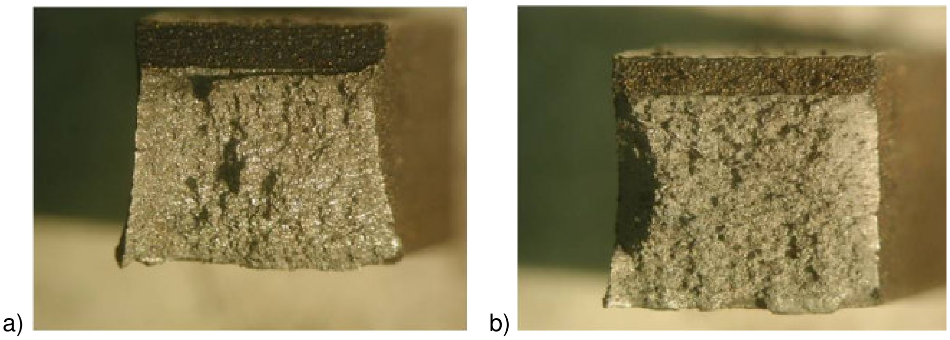

Figure 12 : Fracture surfaces of Charpy specimens a) without and b) with aging (5h at 490°C)

Table 5 : Comparison of SLM versus conventionally produced parts (±95% confidence interval)

	Heat treated [J]	**As-built [J]**
CL50WS on CL M3	4.9±1.1 (5h@480C)	41.9±1.5
MS1 on EOSINT M270	10.1±1.4 (3h@480C) [10]	36.3±4.87 [10]
Conventionally produced	27 (solution annealed and aged 3-6 hours at 480 °C) [11]	

Table 6 : Comparison of SLM versus conventionally produced 18Ni-300 (±95% confidence interval)

	E (Young Modulus) GPa	**Ultimate Tensile Strength [MPa]**	**Elongation at break [%]**	**HRC**
SLM as-built	163 ± 4.4	1290 ± 112.20	13.3 ± 1.86	40
SLM aged 5h@480°C	189 ± 2.8	2217 ± 71.9	1.6 ± 0.26	58
DMLS EOS [1]	180 ± 20*	1100 ± 100*	8 ± 3*	33-37*
DMLS EOS after age hardening [1]		1950 ± 100*	2 ± 1*	50-54*
Wrought [11]	180	1000-1170	6-15	35
Solution annealed (1h at 815°C) and aged (3h at 480°C) [9, 11]	190 [11]	2050 [9]	7 [9]	52 [11]

**not indicated in [1] how the variations are calculated or estimated*

Parts produced on an EOSINT M270 (DMLS) machine equipped with a fiber laser and without laser re-melting exhibit similar mechanical properties to those of the parts produced on a Concept Laser M3 Linear machine equipped with an Nd:YAG laser with laser re-melting. However, the ultimate tensile strength and hardness are higher with Concept Laser parts both for aged and as-built cases. Elongation at break is significantly reduced for both groups of parts produced on Concept Laser and EOS machines being 1-2%. Without any heat treatment, Concept Laser parts exhibit higher elongation than EOS parts of about 5%.

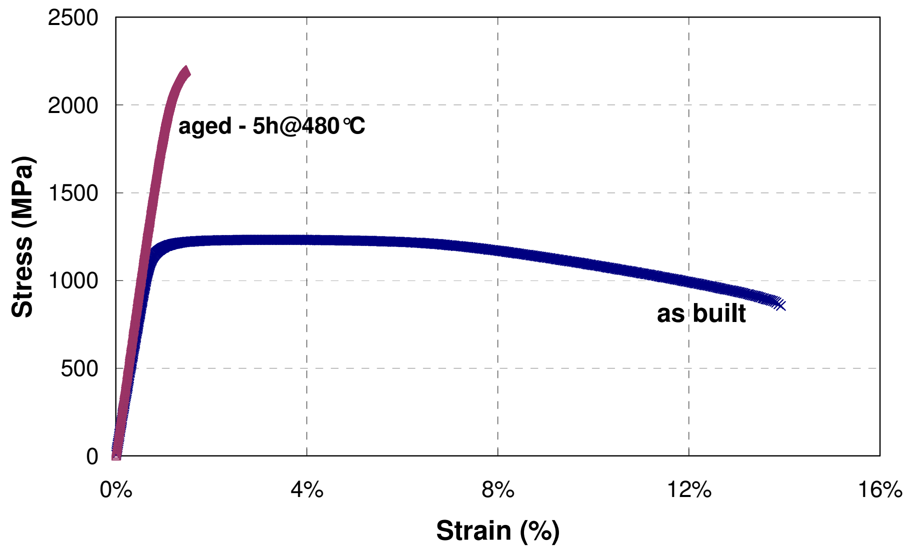

Figure 13 : Stress-strain curve for tensile specimens

Conclusions

In this study, selective laser melting of maraging steel 300 was taken under investigation for many aspects. The effect of different process parameters, namely the scan speed and layer thickness, is studied on the obtained density and surface quality. It is concluded that the porosity increases as the scan speed and layer thickness rise due to lower energy input. To achieve a high density, there is a certain threshold for the energy density and below that the density decreases with decreasing energy density. Above the threshold, the density is not significantly affected by increasing energy densities in the tested range. The effect of the scan speed on the relative density is found to be important especially at high scan speed. As expected, the macro hardness results showed that the porosity decreases the hardness. The influence of the scan speed and layer thickness on the micro hardness is found to be insignificant. Thus, in order to demonstrate the capability of the SLM process yielding good mechanical properties, the maximum density should be attained in the specimens. Applying laser re-melting after every layer is a good solution to increase the density at a cost of higher production times. With this technique, specimens produced by SLM did not depict any aligned porosity or irregularity.

The effect of aging is tested on specimens produced with a hybrid processing of SLM and laser re-melting. Different aging times and temperatures are tested to find out the best combination: 5 hours at 480°C is found out to give high hardness within a relatively short time. With aging tests, it is seen that keeping the specimens at a prolonged times may deteriorate the material properties due to overaging. Mechanical properties are also evaluated by tensile and Charpy impact testing. It is found that the strength and hardness achieved with SLM are higher than that of conventionally produced parts due to natural aging that takes place during SLM and re-melting. There may be other reasons such as nitrogen and oxygen pick up during melting and solidification. The impact toughness of SLM maraging steel 300 parts is however lower. It may be concluded that it is possible to produce dense parts of 18Ni(300) maraging steel with superior strength and hardness. However, more research is needed to find the cause for the low ductility and Charpy impact energy for SLM parts after aging.

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