

EFFECT OF POWDER RECYCLING ON THE CHEMICAL COMPOSITION, MICROPURITY, AND POROSITY OF M300 MARAGING STEEL PRODUCED BY SELECTIVE LASER MELTING

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Powder recycling is widely applied in Selective Laser Melting (SLM) to reduce material costs and waste; however, repeated reuse may influence the characteristics of additively manufactured components. This study investigates the effect of powder recycling on the chemical composition, micropurity, and porosity of M300 maraging steel produced by SLM. Virgin and recycled powders were processed under identical conditions using a Renishaw AM500 system. The chemical composition of the printed samples was determined by glow discharge optical emission spectroscopy (GDOES), while powder morphology, defects, and micropurity were examined using scanning electron microscopy. Porosity was quantified by image analysis following a procedure comparable to ASTM. The results revealed measurable changes in chemical composition associated with powder recycling, particularly reduced nickel content and increased aluminum, silicon, and chromium concentrations. Despite these variations, both material conditions exhibited very low and comparable porosity levels. Typical SLM-related defects, including pores, keyholes, and microcracks, were observed in both cases. The findings indicate that recycled M300 maraging steel powder can be reused in

SLM without a significant effect on porosity or defect formation, provided that powder quality is continuously monitored..

Keywords

3D printing, SLM, recycled powder, porosity, M300

1 INTRODUCTION

Additive manufacturing (AM), particularly Selective Laser Melting (SLM), has become an increasingly important technology for producing complex metallic components. One of its main advantages is the ability to achieve high geometric accuracy while using material efficiently [Peng 2021, Yap 2015, Mesicek 2021]. In the SLM process, metal powder is selectively melted layer by layer, which makes it possible to produce parts with complex internal structures. Such geometries are often difficult, or even impossible, to manufacture using conventional production methods. Among the materials commonly processed by SLM, M300 maraging steel has attracted considerable interest. This alloy is known for its high strength, good toughness, and dimensional stability, which makes it suitable for demanding applications in fields such as aerospace, tooling, and energy industries [Kolomy 2023, Ronda 2022].

The final quality of SLM components depends strongly on the characteristics of the powder used in the process. Particle morphology, chemical composition, and purity of the powder are particularly important. Gas-atomized powders are widely used because they typically have a near-spherical shape and good flowability. Even so, imperfections can still appear during powder production. These may include satellite particles, irregularly shaped particles, or surface contamination. Such features can influence powder spreading during printing and affect the packing density of the powder bed. As a result, the stability of the melt pool may also be affected, which can contribute to defect formation and changes in the microstructure of printed parts [Měšiček J 2022, Li 2024].

In practical applications, powder recycling is commonly used in SLM systems. This approach helps reduce material costs and supports more sustainable manufacturing by limiting waste. However, repeated recycling of powder can gradually alter its characteristics. For example, oxidation of reactive elements may occur, and contamination can accumulate over time. Small changes in chemical composition may also appear after multiple reuse cycles. These effects can influence the microstructure of printed components and increase the probability of defects. Previous studies have reported elemental redistribution during powder reuse, particularly for elements such as aluminum, silicon, and chromium. In addition, oxide inclusions may form in reused powder. Nevertheless, the extent of these effects often depends on the specific material and processing conditions and therefore requires further investigation.

For M300 maraging steel, maintaining a stable chemical composition is especially important. Even minor variations in alloying elements may affect phase stability as well as the overall behavior of the material during processing. Because of this, it is necessary to compare virgin powder with recycled powder and to analyze the properties of components produced from both. Such comparisons can help determine whether recycled powder can be safely used in industrial SLM applications without reducing part quality [Mechali 2024, Mateev 2025, Mechali 2025].

This study specifically examines the development of chemical composition, micropurity, and porosity in recycled M300 maraging steel, an aspect that has not been well explored in

prior research, which often emphasizes mechanical qualities or powder shape. This comprehensive methodology is the primary innovation of current research, setting it apart from the prior literature.

2 MATERIAL AND METHODS

2.1 Morphology of the powder

M300 maraging steel powder was supplied by Carpenter Technology Corporation (Renishaw plc, Wotton Under Edge, UK), and recycled powder was used after several printing cycles. SEM was used to study powder particles. Figure 1 shows spherical M300 virgin and recycled powder particles.

Additionally, many particles have satellites connected to their surfaces. The virgin and used powders show that the gas atomization technique produced non-spherical particles. Satellites are also considered manufacturing flaws. Variable cooling rate, surface tension, and inappropriate atomization settings create satellites in powders. In this case, gas atomization generated the satellites. Satellites were also found in recycled powder after selective laser melting. Due to surface changes during recycling, smaller particles bind to bigger ones and create satellites. The chemical composition was investigated using EDS (Table 1).

Table 1. Chemical composition of the M300 maraging steel (wt.%) [Mechali 2024]

Element	Al	Ni	Co	Mo	Ti	Si	Fe
Manufacturer	-	17-19	7-10	4.50-5.20	0.30-1.20	0.08	Bal
EDS analysis virgin	0.73	16.86	9.32	3.85	0.88	0.35	68.01
EDS analysis Recycled	1.39	17.90	9.12	4.55	0.80	0.24	65.92

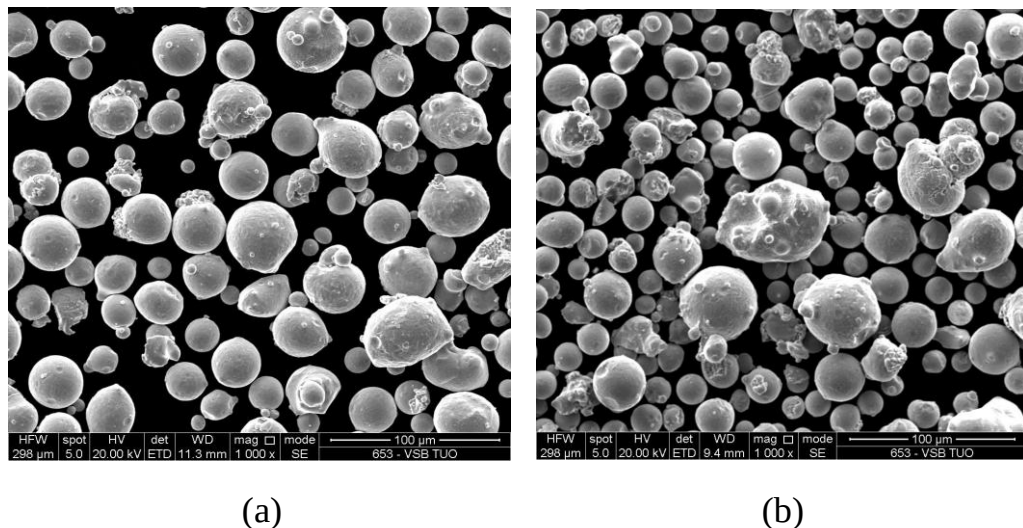


Figure 1. M300 maraging steel powder morphology of the particles (SEM) with 500 x magnification (a) virgin powder (b) recycled powder

2.2 3D printing and printing parameters

The samples were constructed using an SLM, the Renishaw AM500 3D printer. The printing machine has a laser with a maximum power rating of 500 W. The scanning approach was stripe. Two samples (20 x 20 x 20 mm) were printed for porosity and micropurity testing, and two more for chemical composition testing. The printing facility was separated into two buildings, one for virgin powder and the other for recycled powder. Table 2 details the printing process.

Table 2. Fabrication parameters [Mechali 2024]

Parameter	Value
Laser power	250 W
Printing strategy	Stripe
Hatch spacing	0.11 mm
Scan speed	650 mm/s
Preheat temperature	Ambient
Layer thickness	50 µm

3 RESULT AND DISCUSSION

3.1 Chemical composition of samples determined by GDOES analysis

The chemical composition of the printed samples was verified by GDOES analysis. The average values of the element representation from five measurements are given in Table 3; the deviations from the mean values were below 0.5%; in isolated cases they exceeded 2.5%. GDOES is an abbreviation for Glow Discharge Optical Emission Spectroscopy. The principle of the method is the interaction of matter particles with electromagnetic radiation. The sample is placed in a discharge tube and conductively connected to the cathode. The discharge tube is filled with a working gas, most often argon, and after switching on a high voltage, a glow discharge is generated. Argon ions from the glow discharge plasma are accelerated to the surface of the sample, where they impinge on it, and with their high energy, they knock atoms off the surface. The ejected atoms enter the plasma region, where they are excited by collisions with electrons and emit characteristic radiation upon subsequent deexcitation. The

atomic emission spectrum is composed of the spectra of the elements present in the sample.

Table 3. Results of GDOES analysis

Element	Virgin [wt. %]	Recycled [wt. %]
C	<0.005	<0.005
Mn	0.029	0.018
Si	0.032	0.078
P	0.016	0.016
S	0.005	0.005
Cr	0.029	0.121
Ni	19.71	18.63
Mo	5.37	5.21
Cu	0.029	0.028
Ti	0.636	0.688
Co	7.71	7.24
B	0.004	0.004
Pb	0.025	0.022
V	<0.005	<0.005
W	<0.005	<0.005
Zr	0.025	0.023
Al	0.059	0.266
Nb	<0.005	<0.005

The emission spectrum is then analyzed by an optical spectrometer. Chemical analysis showed that the recycled powder sample contains less nickel than the virgin powder (virgin – 19.71 wt.%; recycled – 18.63 wt.%); on the contrary, there is more silicon (virgin – 0.032 wt.%; recycled – 0.078 wt.%), chromium (virgin – 0.029 wt.%; recycled – 0.121 wt.%), and especially aluminum (virgin – 0.059 wt.%; recycled – 0.266 wt.%). The other elements present are represented in both samples approximately equally, with minimal differences. These compositional changes are consistent with phenomena commonly reported during powder reuse in selective laser melting, such as selective evaporation of alloying elements and oxidation of reactive elements during repeated thermal exposure. Although the observed differences in chemical composition are relatively small, they may influence subsequent microstructural evolution and defect formation during the SLM process. Therefore, monitoring chemical composition changes in printed components is essential when evaluating the suitability of recycled powders for repeated industrial use.

3.2 Porosity and purity

The porosity of the fabricated samples was determined. Digital image analysis was conducted with ImageJ software in accordance with the technique outlined in ASTM E1245. The investigation included many randomly chosen fields, using uniform processing settings and statistical assessment to guarantee the correctness and reliability of the findings [Hlinka

2020]. The porosity was quantitatively assessed at three distinct depths inside the samples by image analysis to account for any differences during the construction and to provide a more representative and accurate evaluation of the material. Optical micrographs were captured at a magnification of 500× without etching. This magnification was intentionally selected to reduce the influence of local pore clustering and to obtain a representative evaluation of pore distribution. Representative micrographs are presented in Figure 2.

Table 4. Average porosity values for each sample

Sample	Average porosity (%)
Virgin section perpendicular	0.11 ± 0.02
Virgin section parallel	0.11 ± 0.00
Used section perpendicular	0.38 ± 0.22
Used section parallel	0.28 ± 0.10

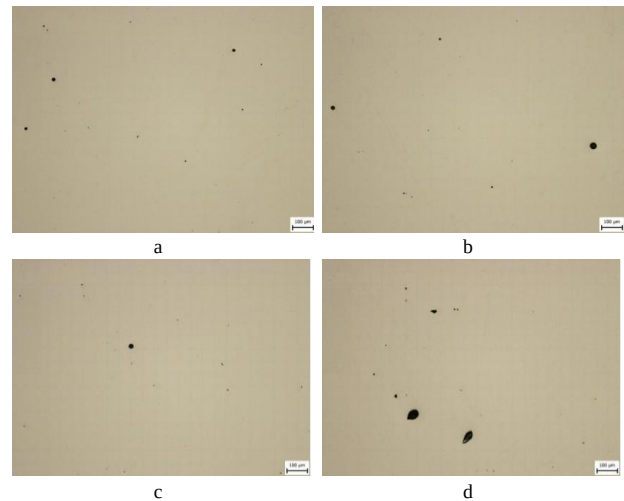


Figure 2. Micro-images of surfaces of samples used for porosity determination with 500× magnification: (a) virgin powder section perpendicular to the printing plane; (b) recycled powder section perpendicular to the printing plane; (c) virgin powder section cut Parallel to the printing plane;(d) recycled powder section cut parallel to the printing plane.

Table 4 shows the average porosity results from repeated observations at three depths. For cross-sections perpendicular to the build direction, porosity values of 0.11% were obtained for samples produced from virgin powder and 0.38% for recycled powder, respectively. In contrast, cross-sections parallel to the build direction exhibited porosity values of 0.11% for virgin and 0.28% for recycled powder. These porosity levels were higher than values reported in the literature for SLM-processed M300 maraging steel. For instance, porosity values of approximately 0.07% were reported in [Mechali 2024]. Upon comparing our findings on the porosity of M300 maraging steel to the data presented in the publication [Ronda 2022] by Ronda et al., it was found that they reported a porosity range of 0.12% to 1.12%. Recycled powder was investigated by Sun et al. in [Sun 2021] and provided values of 1.0% at the horizontal cross-section and 1.2% at the vertical cross-section. This shows that the porosity is still in the range of SLM M300 maraging steel. Reduced porosity is directly related with higher mechanical

qualities in additively made M300 maraging steel, since it lowers stress concentration sites and delays fracture initiation, hence increasing tensile strength and fatigue resistance [Adamidis 2026, Pérez-Gonzalo 2023, Hermann Becker 2016].

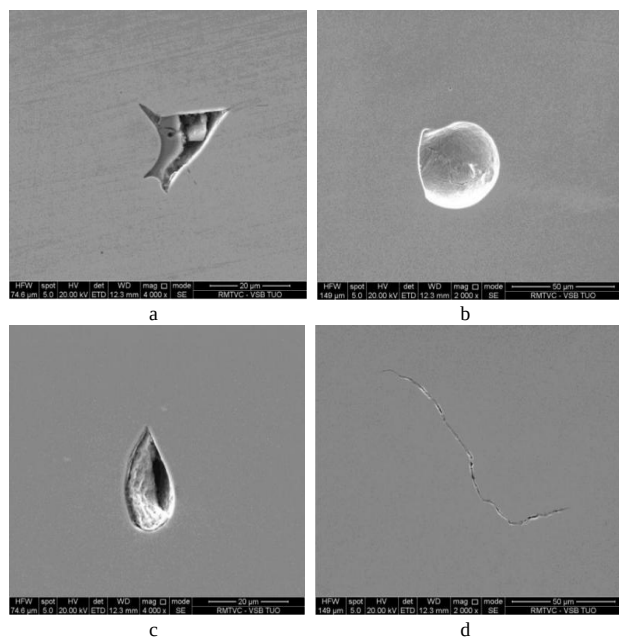


Figure 3. Defects in the recycled powder sample SEM (a) gas pores; (b) irregular cavities; (c) Keyhole; (d) microcrack.

SEM observations of samples produced from recycled powder (Figure 3) revealed a broader variety of defects compared to virgin specimens. In addition to gas pores and irregular cavities, keyhole-type defects and microcracks were occasionally observed. These defects are typically associated with incomplete melting, excessive local energy density, or the presence of foreign particles interfering with stable melt pool formation. Microcracks were also locally detected in both virgin and recycled powder samples. These microcracks are likely associated with thermal gradients and residual stresses generated during rapid heating and cooling cycles inherent to the SLM process. The observed defects were distributed heterogeneously within the material; however, no systematic differences in defect type or density were identified between samples fabricated from virgin and recycled powders. Overall, the morphology, distribution, and frequency of defects were comparable for both material conditions, indicating that powder recycling did not significantly promote defect formation under the applied processing parameters. These observations suggest that the selected SLM processing conditions were effective in maintaining a stable melt pool and adequate densification regardless of powder reuse. Powder oxidation has been discovered as a major element impacting defect creation in additive manufacturing, since it changes melt pool dynamics and encourages the production of porosity and contamination within the material [Mechali 2024, Hermann 2016, Leung 2019].

4 FUTURE WORK AND LIMITATIONS

The current research has certain limitations. Each condition was studied with a single sample, and a restricted number of measurements (five per sample) were conducted. While mean values and standard deviations were computed to enhance the credibility of the data, a more comprehensive statistical analysis proved impractical. Consequently, the findings must be regarded with circumspection. Subsequent research will concentrate on augmenting the quantity of samples and measurements to provide a more thorough statistical analysis.

5 CONCLUSIONS

This study evaluated the effect of powder recycling on the chemical composition, micropurity, and porosity of M300 maraging steel components produced by Selective Laser Melting. A comparative analysis of virgin and recycled powders revealed measurable changes in chemical composition, particularly a reduction in nickel content and an increase in aluminum, silicon, and chromium levels, as determined by GDOES analysis. These changes are attributed to oxidation and elemental redistribution occurring during repeated powder reuse. Despite these compositional variations, both virgin and recycled powders resulted in components with very low and comparable porosity levels, indicating that powder recycling did not adversely affect densification under the applied processing conditions. Micropurity analysis showed the presence of typical SLM-related defects, including pores, keyhole-type voids, and microcracks, in both material conditions. The type, morphology, and distribution of these defects were generally similar for samples produced from virgin and recycled powders. Overall, the results demonstrate that recycled M300 maraging steel powder can be reused in the SLM process without a significant negative impact on porosity or defect formation. Nevertheless, the observed changes in chemical composition highlight the importance of continuous monitoring of powder quality during recycling to ensure stable processing conditions and consistent material performance in industrial SLM applications.

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