UNIVERSITY OF TURKU

# Cold-Welding of Aluminium in EOS M 400 Metal 3D Printer


Materials Engineering
Faculty of Technology


Bachelor's thesis


Otto Rautava


15.5.2025

Turku

# Abstract

Bachelor's thesis

**Subject**: Metallurgy and Additive Manufacturing

**Author(s)**: Otto Rautava

**Title**: Cold-Welding of Aluminium in EOS M 400 Metal 3D Printer

**Supervisor(s)**: PhD Emilia Palo

**Number of pages**: 28 pages

**Date**: 15.5.2026

Aluminium is used in additive manufacturing (AM) to produce lightweight high-performance components, especially for automotive and aerospace industries. The EOS M 400 3D printer for metal solutions is used for industrial serial production of large metal parts. The printer operates by using powder bed fusion (PBF) technique, where a laser beam fuses a thin layer of metal powder layer-by-layer into the wanted structural dimensions.

Aluminium is softer than the steel parts of the powder dispenser system of the printer and its adhesion to the parts is therefore subject for research. The adhesion event is expected to be some form of cold-welding, which is a process that joins similar metals using high pressure without melting the materials. The friction caused by the mechanical work done by a rotary powder feeder in the dispenser system has been observed to adhere some aluminium alloys on the surrounding scraper plates.

To investigate the possibility of the adhesion of aluminium on the scraper plates and how it might interfere with the functions of the dispenser, an experimental study was devised. During the experiment, altogether approximately 610 kg aluminium powder was passed through the rotary feeder assembly, and the scraper plates were weighed and thickness measured to determine the amount of adhered aluminium compared to the amount of powder passed through.

Adhesion of aluminium on the scraper plates was visually detected after the experiment. However, the amount of adhered aluminium was small and not reliably observed by the measurements. Due to the limited results of this research project, no definitive conclusions could be made about how much the cold-welded aluminium affects the dispenser system of the EOS M 400 3D printer. Nonetheless, the results are consistent with the hypothesis. The adhesion of aluminium on to the scraper plates is expected to be some form cold-welding.

**Keywords**: 3D printing, additive manufacturing, aluminium, cold-welding

Kandidaatintutkielma

**Aihe**: Metallurgia ja ainetta lisäävä valmistus

**Tekijä(t)**: Otto Rautava

**Nimi**: Alumiinin kylmähitsaantuminen EOS M 400 3D-metallitulostimessa

**Ohjaaja(t)**: FT Emilia Palo

**Sivumäärä**: 28 sivua

**Päivämäärä**: 15.5.2026

Avainsanat: 3D-tulostus, alumiini, kylmähitsaus, lisäävä valmistus

Alumiinia käytetään lisäävässä valmistuksessa (AM) erityisesti auto- ja ilmailuteollisuudessa kevyiden ja kestävien osien valmistukseen. EOS M 400 3D -metallitulostinta käytetään suurten metalliosien teolliseen sarjatuotantoon. Tulostin käyttää jauhepetifuusiotekniikkaa (PBF), jossa lasersäde sulattaa ohuen metallijauhekerroksen kerros kerrokselta haluttuun rakenteelliseen muotoon.

Alumiini on pehmeämpää kuin tulostimen jauheenannostelijan teräsosat, jonka vuoksi sen kiinnittyminen laitteen osiin on tutkimuksen kohteena. Kiinnittymisen odotetaan olevan jonkinlaista kylmähitsausta, joka yhdistää samanlaisia metalleja korkeassa paineessa sulattamatta kuitenkaan materiaaleja. Annostelujärjestelmän pyörivän jauheensyöttölaitteen tekemän mekaanisen työn aiheuttaman kitkan on havaittu kiinnittävän joitakin alumiiniseoksia laitetta ympäröiviin haittalevyihin.

Kokeellinen tutkimus suunniteltiin alumiinin tarttumista haittalevyihin ja sen mahdollisten aiheuttamien laitehäiriöiden analysoimiseksi. Kokeen aikana pyörivän syöttölaitteen läpi ohjattiin yhteensä noin 610 kg alumiinijauhetta. Haittalevyt punnittiin ja niiden paksuudet mitattiin, jotta voitiin määrittää hitsaantuneen alumiinin määrä verrattuna läpi kulkeneen jauheen määrään.

Alumiinin tarttuminen haittalevyihin oli selvästi nähtävissä kokeen jälkeen. Tarttuneen alumiinin määrä oli kuitenkin niin pieni, ettei sitä voitu luotettavasti havaita mittauksissa. Tutkimusprojektin rajallisten tulosten vuoksi ei voitu tehdä lopullisia johtopäätöksiä siitä, kuinka paljon kylmähitsaantunut alumiini vaikuttaa EOS M 400 3D -tulostimen annostelujärjestelmään. Tulokset ovat kuitenkin yhdenmukaisia hypoteesin kanssa. Alumiinin tarttumisen haittalevyihin oletetaan olevan jonkinlaista kylmähitsausta.

**Avainsanat**: 3D-tulostus, alumiini, kylmähitsaus, lisäävä valmistus

## Acknowledgements

I would like to express my gratitude to my supervisor at the University of Turku, Dr. Emilia Palo, for her patience and guidance during my work on the thesis. I want to thank my supervisors at EOS Finland Oy, Eero Virtanen and Jukka Simola, for their expertise and help during the empirical work. Thanks also to EOS Finland Oy and their entire personnel.

I also want to extend my gratitude to my family, for their never-ending support and faith in me.

15.5.2026
Turku

Otto Rautava

## Abbreviations

| | |
|---|---|
| Al | Aluminium |
| AM | Additive Manufacturing |
| CAD | Computer-Aided Design |
| PBF | Powder Bed Fusion |
| DMLS | Direct Metal Laser Sintering |
| FCC | Face-Centred Cubic crystal structure |
| SEM | Scanning Electron Microscope |
| Si | Silicon |
| DAS | Dendrite Arm Spacing |
| SDAS | Secondary Dendrite Arm Spacing |
| HSS | High Speed Steel |

## Table of contents

# 1 Introduction

The EOS M 400 is a 3D printer for metal solutions. It is used in industrial production by using direct metal laser sintering (DMLS) process, especially meant for larger metal parts. [1] The printer is manufactured by Electro Optical Systems GmbH (EOS), located in Germany, which specializes in additive manufacturing of metals and polymers. The office of EOS Finland Oy in Turku concentrates on the AM of metals.

Additive manufacturing enables the production of parts with complex structures because of the extensive customization capabilities and design flexibility it brings. The manufacturing of personalized components becomes more cost-efficient, prototyping becomes easier and material waste decreases. Nonetheless, AM technology does not come without its own unique problems, including processing defects and machine maintenance. [2]

The phenomenon of cold-welding has been detected in the dispenser system of the EOS M 400 metals 3D printer. The adhesion of aluminium on scraper plates dosing the powder into the process chamber of the printer has been noticed with at least AlSi10Mg aluminium powder as seen in figure 1. The amount of aluminium powder cold-welding onto the plates and how it affects the performance of the printer is subject for research and is done with a development-stage EOS Al8X1 aluminium powder. This report concentrates solely on AM using the EOS M 400 3D-printer.

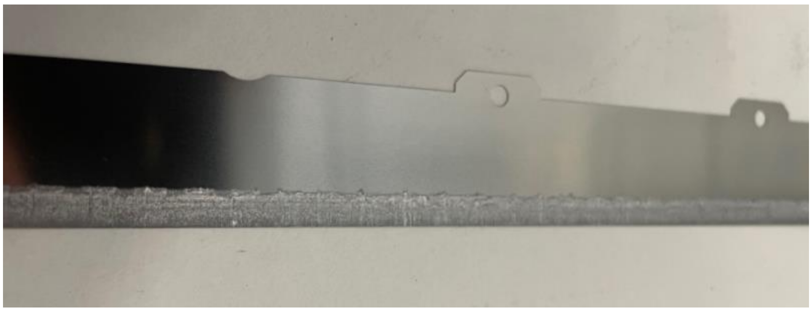

Figure 1. AlSi10Mg adhered on the wider scrape plate of EOS M 400 rotary feeder assembly.

## 1.1 Additive manufacturing using the EOS M 400 3D printer

Additive manufacturing is used to produce complex three-dimensional structures. The EOS M 400 3D printer uses powder bed fusion (PBF) technique which is one of the most widely used in AM. In PBF, the powder acts as a support structure for the layer-by-layer building process. [3] The process uses a high-wattage laser moving across the surface to sinter a thin layer of powder. The powder can be heated together with the building platform, but its purpose is not to melt metal, but rather to reduce formation of residual stresses or other unwanted phenomena during the printing process. Focused laser beam is used to melt the powder particles and fuse them together with previous layers, essentially by micro-welding.[4,5]

PBF is divided into different categories, of which the EOS M 400 printer uses the DMLS method, developed in-house. The DMLS method can be used to build structures out of any engineering material. [5] Based on a digital 3D model CAD-file, the powder material is melted layer-by-layer using a laser beam. [6] The CAD model is converted into a cross-section of the part and saved as an STL file. Figure 2 displays the powder dispenser, in which the powder is stored, and the process chamber where the building process takes place. The metal powder is delivered from the dispenser through a rotary feeder assembly onto a recoater, which spreads a thin layer, usually 40-80 $\mu$m [7], of powder onto the powder bed. The laser fuses the powder as per the cross-sectional data from the STL file. The powder is then added layer-by-layer until the building process is complete. After each layer is built, the building platform lowers, so that a new powder layer can be formed by the recoater.[3]

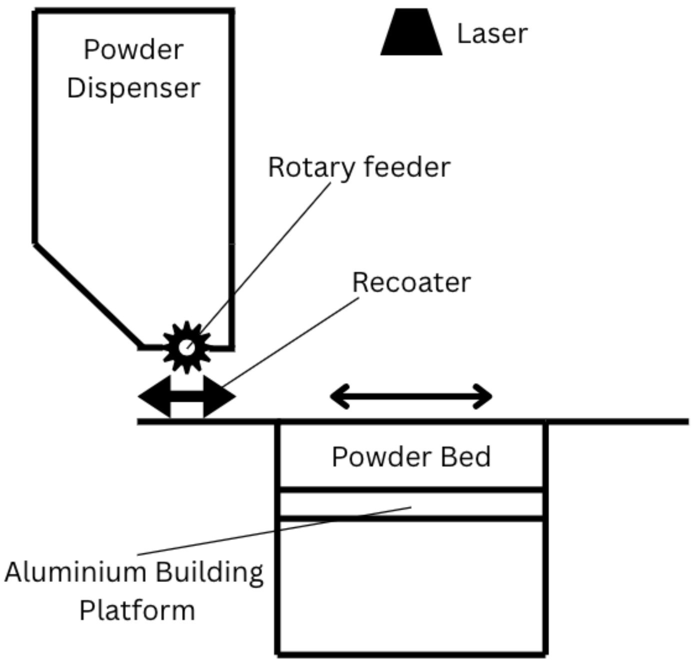


Figure 2. EOS M 400 dispenser system and process chamber.

The M 400 uses the dispenser system to store and distribute the powder on the building platform. The amount of powder required for a building process is measured out using a rotary feeder assembly, shown in figure 3, at the bottom of the dispenser. On the container side and the powder output side of the rotary feeder, there are steel scraper plates of different sizes. These plates are used to limit the amount of powder distributed by the dispenser. This is also where the cold-welding of the aluminium powder is expected to happen.

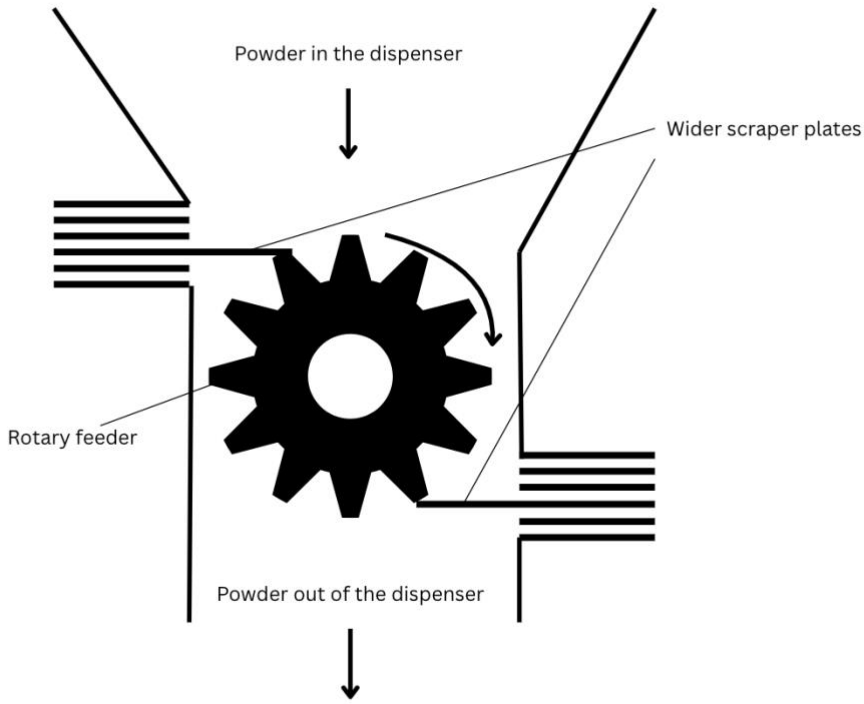


Figure 2. EOS M 400 rotary feeder assembly.

When the cold-welded aluminium forms on the wider scrape plates, it decreases the gap between the rotary feeder and scraper plate. Over time, the thickness of the cold-welded layer of aluminium increases. The contact between the rotary feeder and the plate generates friction causing wear on the components and strains the motor rotating the rotary feeder. In extreme cases, it may prevent the rotating movement of the rotary feeder which requires maintenance.

In this thesis, AI was used solely for finding references. All the images in this thesis were created by the author.

### 1.2 Aluminium in AM

Aluminium alloys are often used in automotive and aerospace industries as well as in shipbuilding and modern architecture, because of their high-performance and lightweight applications. Aluminium is commonly alloyed with other elements as the applications of pure aluminium itself are limited. The elements most often used include silicon, copper, magnesium and manganese. [2]

While traditional subtractive processing struggles with producing complex geometries, internal structures and material-efficient components, AM enables the fabrication of intricately designed parts while reducing component count and overall cost. However, AM of aluminium alloys is highly complex. During laser–powder interaction, solid, liquid, vapor, and plasma states coexist. The process involves fast cooling rates as the laser forms and solidifies a micron-scale melt pool. Heat dissipates quickly through the built supports and prior layers, accelerating solidification and limiting thermal stresses, but also introducing significant physical and chemical challenges across multiple scales. These challenges may affect lifecycle and performance as AM aluminium alloys are susceptible to columnar cracks and grains. [2]

Aluminium's high ductility is caused by its face-centred cubic (FCC) crystal structure. This structure has 12 slip systems making these materials highly ductile allowing them to deform easily under stress. [8] The high surface energy of aluminium enables atoms to form strong metallic bonds promptly with other aluminium atoms when oxide barriers are absent. [9]

## 1.3 Cold-welding

The adhesion process taking between the aluminium powder and the steel scraper plate remains poorly understood. It is likely to consist of some form of cold-welding, which is a solid-state welding process where the weld is the result of pressure. Friction welding is a form of cold-welding where the friction between two surfaces generates enough heat to forge two surfaces together under high pressure.[10]

The sequence of events leading to cold-welding can be described in four stages: oxide layer disruption, bare metal contact, atomic bond formation and junction shearing and material transfer. Aluminium is protected by a thin oxide film which forms almost instantly when exposed to air. The $Al_2O_3$ layer is usually 2-10 nm thick.[11] In the dispenser, the rotary feeder scrapes the protective layer away under contact pressure and mechanical motion. Inside the DMLS printer, the bare aluminium cannot re-oxidise because of the inert nitrogen atmosphere. This exposes the chemically clean and reactive metal surfaces. At these junctions, the true contact area is subjected to high local pressure, often exceeding the material's yield strength. The cold-welding event occurs when atomic bonds form at these contact points. The metal atoms from opposing surfaces are close enough for metallic bonds to spontaneously form. Under continued motion, these micro-welds shear. Depending on the relative strength of the junction in relation to the bulk material, shearing occurs within the softer aluminium by material transfer and wear debris. [12–14]

Galling is the term used for more aggressive adhesive wear when chunks of material transfer from one surface to the other, leaving a rough, torn surface texture. [14] As not all metals are equally prone to cold-welding and galling, there are material factors that must be taken into consideration. Highly ductile metals deform easily at asperity contacts, increasing real contact area and the probability of junction formation. Lower hardness entails that asperities yield more readily. Higher surface energy increases adhesive forces. Aluminium has high surface energy and forms strong metallic bonds. [12,13,15]

A secondary cold-welding mechanism involves the aluminium powder particles themselves. Powder particles have an oxide layer from the gas atomisation process during powder manufacture. Under the pressure applied by the rotary feeder, particles in contact deform, cracking and fragmenting the oxide layer and exposing bare aluminium from adjacent particles to one another. In the nitrogen-bearing atmosphere inside the printer, the oxide layer cannot reform. The result is inter-particle cold-welding, which manifests as powder agglomeration, where loose powder clumps rather than flowing freely. This results in feed system problems. If the powder delivery mechanism involves any mechanical compression, agglomerated powder can bridge or jam, which is recognised as a challenge in aluminium AM. [16]

A scanning electron microscope (SEM) image was taken of cold-welded AlSi10Mg on a scraper plate, shown in figure 3. In this image, dendrite growth and the aluminium eutectic structure can be observed. Particularly for Al-Si alloys, this kind of dendritic growth can be observed along the crystallographic directions and are seen in the image as darker, reticulate growths. These growths form as the aluminium solidifies at a relatively high speed. [17] The distance between the thicker trunks is known as dendrite arm spacing (DAS) and the distance between the thinner branches is referred to as secondary arm spacing (SDAS). The solidification speed correlates with the SDAS. After the dendrite structure has formed and the aluminium quantity decreased, the silicon-rich molten state begins the eutectic solidification. This can be observed in the picture as the mass between the dendrite growths. [18]

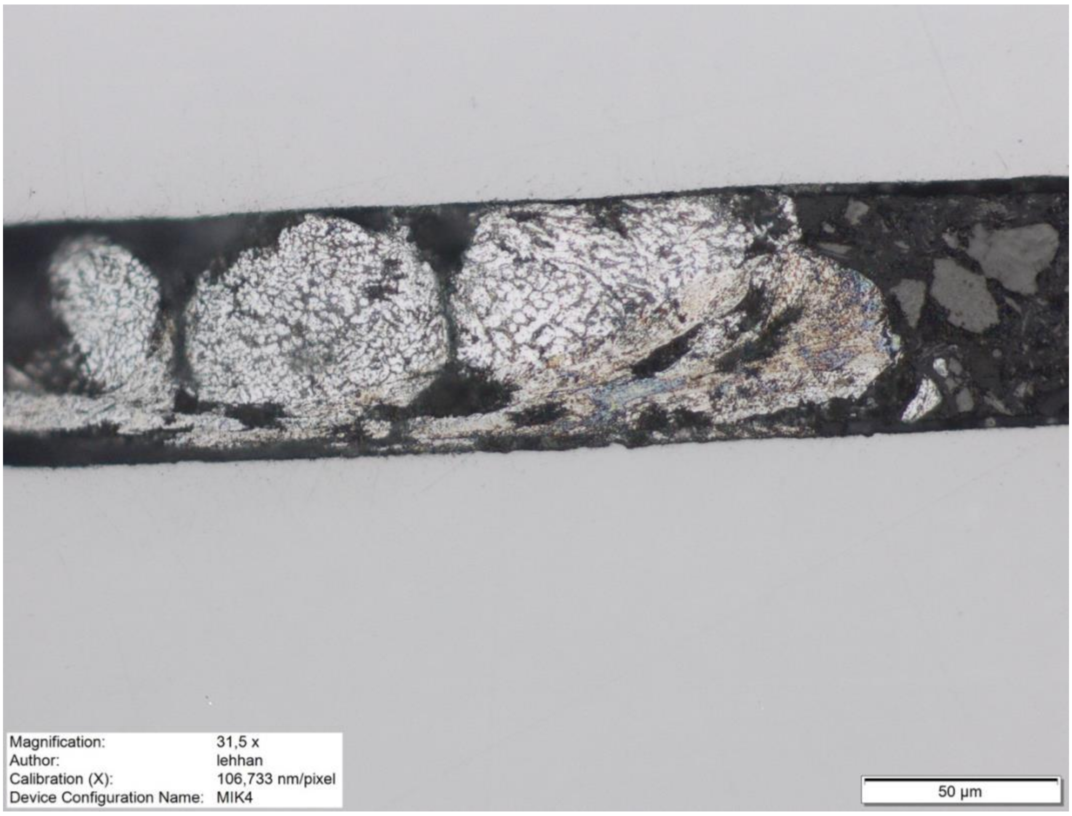


Figure 3. SEM picture of a layer of AlSi10MG aluminium powder adhered on a scraper plate.

# 2 Materials and Methods

The material used for the research project was a soft, low-alloyed EOS Aluminium 8X1 powder. 75 kg of the aluminium powder was reserved for the research project to be used during the building processes.

## 2.1 Powder dispenser

The M 400 powder dispenser is a container sitting on top of the printer. It consists of two parts: the powder container and the rotary feeder assembly. Before the experiments, the dispenser system was taken apart, cleaned and the scraper plates were replaced by new ones. The lid of the dispenser was removed and the powder container emptied and cleaned from any traces of the previous powders used. For powder that may have been contaminated by dirt or other powder materials, the Ruvac Wet Seperator NA35 was used. For aluminium powders, a separate wet separator was used, because of the possibly dangerous reactions with other materials. Ethanol-soaked cloths were used to wipe the surfaces clean. After the container was clean, the dispenser was placed on its side so, that the rotary feeder assembly could be disassembled.

Hex key wrenches were used to open the various sizes of cap head screws. First, the cover of the rotary feeder motor had to be removed to access the motor. The belt of the motor was removed by loosening the screws on the motor support, after which the motor could be put aside using a zip tie to fasten it on the container, where it is not in the way. Eight screws holding the silicon blade frame were unscrewed and the frame set aside. Next, to remove the two metal plates, four screws had to be unscrewed on the top one which secures the thin metal sheet with rake-like tines under it. The sheet was removed by unscrewing the four screws holding it. Finally, the rotary feeder case was detached from the dispenser by unscrewing eight long screws. Care had to be taken so, that the possible powder stuck in the gasket and between the screw sleeves of the rotary feeder case and the dispenser could be vacuumed properly.

The rotary feeder case consists of the rotary feeder that distributes the powder, the scraper plates that restrict the flow of the powder and the case. The plates are located on both sides of the case. For clarity, the sides were named as the inner and outer sides, where the inner side is the one on the dispenser container side and the outer side is where the powder comes out of the dispenser system and onto the recoater. The plates were removed by unscrewing the five screws on the metal plate holding the plates. Attention had to be given to the order of the plates, so that the new ones could be installed in the same arrangement. The new plates were inserted in the same order and screwed on the rotary feeder case. To clean the rotary feeder, it had to be taken out of the case before the new plates were inserted. The four screws on the end of the rotary feeder case were unscrewed, and the rotary feeder was slid out. Cleaning the rotary feeder was performed by using a steel tool with a sharp edge by carefully refining the edges of the rotary feeder. A cloth soaked in ethanol was used to wipe off all the remaining impurities.

After the scraper plates had been replaced, the dispenser was put together. This was done by repeating the same steps as in the disassembling, but in the reverse order. The belt had to be tightened, and the cogwheel sensor had to be set at 0.6 mm from the wheel. This was a crucial step in ensuring that the dispenser worked properly. Ultimately, when the dispenser was ready, it was set in its place on top of the EOS M 400 and tested for any problems. The rotary feeder was rolled 20-100 times to confirm that the motor works and the scraper plates and screws are secured tightly.

The dismantling of the dispenser had to be done every time the scraper plates were measured for the cold-welding of the aluminium powder. For this research project, the dispenser was taken apart three times after certain amounts of powder had passed through the rotary feeder assembly. The amounts of powder for the first, second and third times were 73.8 kg, 140.0 kg and 395.6 kg. respectively. Before every disassembly, the rotary feeder was rotated until all the powder left in the dispenser had passed through. This had to be done to make sure the cleaning was safer, more efficient and the amount of powder gone to waste was minimal.

### 2.1.1 Scraper plate configuration and measurements

There are six scraper plates on both sides of the rotary feeder in a specific order. Out of the six plates, three are 0.3 mm thick and three are 0.2 mm thick. One of the 0.2 mm thick plates is wider than the others and is the one that limits the flow of the metal powder. This was where the cold-welding is visible and can be measured. The order of the scraper plates determines how close the wider plates are to the rotary feeder. The plate orders for both sides are presented in table 1. In the table, the order is from top to bottom, meaning that the top plate is the one furthest away from the rotary feeder and the first to be removed. There were no official instructions for the scraper plate order to be found, so the order is the same as it was when the plates were first replaced.

Table 1. The order of the scraper plates on the inner and outer side of the rotary feeder case from top to bottom.

| Scraper plate order form top to bottom | Inner side scraper plate thickness (mm) | Outer side scraper plate thickness (mm) |
|---|---|---|
| 1 | 0.2 | 0.3 |
| 2 | 0.3 | 0.2 |
| 3 | 0.2 | Wide 0.2 |
| 4 | Wide 0.2 | 0.2 |
| 5 | 0.3 | 0.3 |
| 6 | 0.3 | 0.3 |

The thickness of the scraper plates was measured from five predetermined points, because the thickness of cold-welding can vary at different sections of the plate. The measurements were performed three times for each point to ensure the accuracy of the width. The measurement points are shown in figure 4.

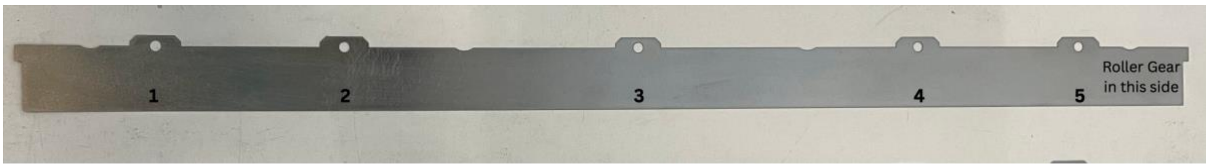

Figure 4. Measurement points on the wider scraper plate.

Before the new scraper plates were installed, the thickness of the wider plate had to be measured. For the measurements, a Mitutoyo IP65 micrometre with a range of 0-25 mm and a margin of error of 0.001 mm was used. The true thickness of the plates was 1-7 µm thicker than nominal thickness of the plates. The thickness is measured every time the dispenser is taken apart. This first measurements gave the reference values of the thicknesses for when the thickness of the cold-welded aluminium layer was measured. The three measurements and the calculated mean are presented in table 2.

Table 2. The measured thicknesses of the inner and outer wide scraper plates and the calculated mean thickness.

| Measuring point | Measurements for the inner scraper plate thickness (mm) | Average thickness of inner scraper plate (mm) | Measurements for the outer scraper plate thickness (mm) | Average thickness of outer scraper plate (mm) |
|---|---|---|---|---|
| 1 | 0.205<br>0.205<br>0.204 | 0.205 | 0.206<br>0.201<br>0.201 | 0.203 |
| 2 | 0.207<br>0.204<br>0.203 | 0.205 | 0.202<br>0.203<br>0.201 | 0.202 |
| 3 | 0.205<br>0.202<br>0.204 | 0.204 | 0.205<br>0.204<br>0.202 | 0.204 |
| 4 | 0.205<br>0.203<br>0.203 | 0.204 | 0.206<br>0.204<br>0.205 | 0.205 |
| 5 | 0.202<br>0.203<br>0.202 | 0.202 | 0.201<br>0.202<br>0.203 | 0.202 |

The masses of the two wider scraper plates were also measured to monitor the amount of aluminium cold-welded onto the plates. To weigh the plates, a Kern PLT 650-3M precision balance was used. The new wider scraper plates were weighed before they were installed to log the initial weight. For the inner and outer plates, the masses were 13.488 g and 13.496 g, respectively. The scraper plates were weighed every time the dispenser was taken apart.

### 2.2 Process

Before the building process could started, the aluminium powder was poured into the dispenser, after which it was lifted in its place on the M 400 printer. The powder was poured into the dispenser using a funnel specifically for aluminium to avoid contaminations from other materials. A Konecranes overhead crane used for the lifting has a weighing scale which was used to weigh the powder. As the mass of the dispenser itself is 54.4 kg, it had to be taken into consideration when calculating the mass of the powder.

The printer was prepared by mounting an aluminium building platform and levelling it to the correct hight which is 0.05-0.1 mm below the recoater blades. High speed steel (HSS) blades were used for the recoater. Preparing of the first layer of powder on the platform was done manually, making sure that the holes for the screws on the platform were filled with powder. Finally, the processing conditions for the building process could be established, which the printer does automatically, and the building process was started.

When the building process was done, the printer was emptied from the powder. Depending on the amount of powder used for the building process, two or three drums were needed to store the powder. The drums were filled using as EOS IPCM-M vacuum with a filter used only for the specific material. The powder was reused to restart the process again. The number of building processes run was not relevant, only the amount of powder, as nothing was built during these processes.

### 2.2.1 Parameters for the building process

The building process created for research purposes was done so, that as little as possible powder goes to waste. Although printing parts during the process would not affect the results, there was no need for it as the cold-welded aluminium formed on the scraper plates surrounding the rotary feeder.

There were three main parameters for the building process. No laser power was required as nothing was being built. Turbine flow was set as low as possible to ensure that the powder did not stir up and go to waste in the filter system of the printer. Fluidization was on during the building process, which means that discharge aid of powder from the powder container is done by introducing a gas flow through the material to reduce its cohesivity.[4]

#### 2.2.2 Powder

The Al8X1 aluminium powder used for this research was still in pre-development and therefore the chemical composition cannot be disclosed. It was used for this research project because the occurrence of cold-welding had been observed using other aluminium powders e.g., AlSi10Mg. The Al8X1 powder being softer than the aforementioned powder, the cold-welding should be more aggressive because of the easier deformation of particles and their oxide layer.

The same aluminium powder vacuumed form the machine after a building process could be reused. There was no need for sieving the powder because oversized particles had not formed, as the powder was not introduced to the laser.

## 3 Results

In total, eleven building processes were done for this research project during which 609.4 kg of aluminium powder went through the rotary feeder assembly. The first time the dispenser was dismantled was after the first building process. This was done to ascertain that the processes worked properly and to determine how much aluminium had cold-welded onto the scraper plates. During this first process, 73.8 kg of aluminium powder had gone through the rotary feeder assembly. The measured thicknesses and weights of the wider scraper plates are presented in table 3. The amount of cold-welded aluminium on plates was insignificant but could be noticed with a bare eye. The results are within the margin of error, and, consequently, any definitive conclusions cannot be made.

Table 3. The measured thicknesses of the inner and outer wide scraper plates and the calculated mean thickness after the first dismantling.

| Measuring point | Measurements for the inner scraper plate thickness (mm) | Average thickness of inner scraper plate (mm) | Measurements for the outer scraper plate thickness (mm) | Average thickness of outer scraper plate (mm) |
|---|---|---|---|---|
| 1 | 0.207<br>0.205<br>0.207 | 0.206 | 0.206<br>0.204<br>0.204 | 0.205 |
| 2 | 0.206<br>0.204<br>0.203 | 0.204 | 0.207<br>0.204<br>0.205 | 0.205 |
| 3 | 0.205<br>0.202<br>0.204 | 0.204 | 0.205<br>0.205<br>0.203 | 0.204 |
| 4 | 0.203<br>0.202<br>0.204 | 0.203 | 0.202<br>0.206<br>0.206 | 0.205 |
| 5 | 0.206<br>0.207<br>0.206 | 0.206 | 0.207<br>0.206<br>0.207 | 0.207 |

The second dismantling was done after three more building processes, after which 140.0 kg more of aluminium powder had gone through the rotary feeder assembly. The results of the measurements presented in table 4 show notable increase of the cold-welded aluminium compared to the first disassembly.

Table 4. The measured thicknesses of the inner and outer wide scraper plates and the calculated mean thickness after the second dismantling.

| Measuring point | Measurements for the inner scraper plate thickness (mm) | Average thickness of inner scraper plate (mm) | Measurements for the outer scraper plate thickness (mm) | Average thickness of outer scraper plate (mm) |
|---|---|---|---|---|
| 1 | 0.210<br>0.211<br>0.210 | 0.210 | 0.209<br>0.209<br>0.208 | 0.209 |
| 2 | 0.211<br>0.210<br>0.209 | 0.210 | 0.207<br>0.207<br>0.202 | 0.205 |
| 3 | 0.211<br>0.208<br>0.209 | 0.209 | 0.206<br>0.208<br>0.208 | 0.207 |
| 4 | 0.214<br>0.217<br>0.216 | 0.216 | 0.208<br>0.205<br>0.206 | 0.206 |
| 5 | 0.208<br>0.210<br>0.210 | 0.209 | 0.205<br>0.207<br>0.205 | 0.206 |

The final dismantling was done after seven more building processes had been completed and 395.6 kg more of aluminium powder had gone through the rotary feeder assembly. The results of the measurements presented in table 4 show an unexpected decrease of the cold-welded aluminium compared to the second disassembly.

Table 5. The measured thicknesses of the inner and outer wide scraper plates and the calculated mean thickness after the third dismantling.

| Measuring point | Measurements for the inner scraper plate thickness (mm) | Average thickness of inner scraper plate (mm) | Measurements for the outer scraper plate thickness (mm) | Average thickness of outer scraper plate (mm) |
|---|---|---|---|---|
| | 0.206 | | 0.206 | |
| 1 | 0.206 | 0.205 | 0.206 | 0.206 |
| | 0.204 | | 0.205 | |
| | 0.209 | | 0.208 | |
| 2 | 0.208 | 0.208 | 0.207 | 0.207 |
| | 0.207 | | 0.206 | |
| | 0.207 | | 0.205 | |
| 3 | 0.204 | 0.206 | 0.204 | 0.205 |
| | 0.206 | | 0.205 | |
| | 0.208 | | 0.207 | |
| 4 | 0.209 | 0.208 | 0.206 | 0.206 |
| | 0.208 | | 0.206 | |
| | 0.206 | | 0.207 | |
| 5 | 0.206 | 0.206 | 0.206 | 0.206 |
| | 0.206 | | 0.206 | |

The difference between the distance of the scraper plates on the inner and outer sides in relation to the rotary feeder noticeably affected the amount of aluminium cold-welded onto the plates. The measurement results support this as well as the figures below, which were taken during the last disassembly. Figure 5 shows the adhesion of aluminium on the wider plate on the outer side of the rotary feeder assembly. The wider plate was situated 0.8 mm above the rotary feeder. The amount of cold-welded aluminium after eleven building processes were still inside the margin of error.

Figure 5. Cold-welded aluminium formed on the wider scraper plate on the outer side of the rotary feeder assembly after eleven building processes.

The wider scraper on the inner side of the rotary feeder assembly is shown in figure 6. The aluminium adhered on the wider plate is more prominent compared to the plate on the other side of the rotary feeder. The plate is situated 0.6 mm above the rotary feeder.

Figure 6. Cold-welded aluminium formed on the wider scraper plate on the inner side of the rotary feeder assembly after eleven building processes.

## 4 Discussion

The results corroborate the hypothesis that the Al8X1 aluminium powder does cold-weld onto the scraper plates of the EOS M 400 metal 3D printer. Even after the first building process and disassembly, the phenomenon was visible, as seen in figure 7. Even though the difference in the amount of adhered aluminium comparing the first and last building processes is not substantial, it must be taken to consideration, that the scraper plates can be used in hundreds of building processes, during which thousands of kilograms of powder go through the rotary feeder assembly. It is probable that during this kind of continuous use, the amount of aluminium adhered to the plates affects the powder delivery. The friction caused by the cold-welded layer may restrict the rotation of the rotary feeder.

Figure 7. Cold-welded aluminium formed on the wider scraper plate on the inner side of the rotary feeder assembly after first building process.

As this research for the bachelor's thesis is part of a larger research project conducted for Electro Optical Systems Finland Oy, more results are yet to come. Future results will help determine whether the cold-welded aluminium affects the rotary feeder and the process of 3D printing and if so, at what scale.

The unexpected difference between table 4 and 5 might be explained by several factors. It could be within the margin of error so, that the accuracy of the micrometre is not enough. It could also be explained by user error. As the micrometre is a handheld device, the position where and how the scraper plate was measured can differ each time it was measured. An unlikely but possible reason could also be that the rotary feeder scrapes off the already adhered aluminium, altering the results.

The way that the cold-weld begins to form on the scraper plates raises questions. One theory is, that there could be a surface defect, e.g. a small cavity, on the surface of the plate. When a powder particle enters the cavity, it could get trapped in it. This would increase the chance of more particles getting caught around the defect, causing more friction between the rotary feeder and the plate. This increases the conditions of cold-welding. The second possible way for cold-welding to happen could be accumulation of powder. When the powder builds up on a specific area on the surface of the plate, it forms a layer. This also increases friction, increasing the possibility of cold-welding.

The research was conducted using a previously used rotary feeder. This can affect the results if there were any cracks or dents on the edges on the rotary feeder. These defects could alter the powder buildups, either increasing or decreasing the formation. To prevent the formation of adhered aluminium, the rotary feeders features could also be redesigned so, that its shape would cause less adhesion of the powder.

To test for any problems with the dispenser after the reassemble the rotary feeder should be rolled 20-100 times. In case of any problems, the dispenser should be taken down and inspected first by checking the cogwheel censor. If the cogwheel is at its correct distance of 0.6 mm, the steps to take the dispenser apart must be repeated and checked for any looseness in the screws.

### 4.1 Possible improvements for current research

As previously mentioned, the rotary feeder was previously used. It is probable that the aluminium powder adheres on the rotary feeder as well. It was difficult to tell if there were any cold-welded aluminium already on the rotary feeder when it was first disassembled and cleaned. To investigate the formation of adhered aluminium, a new rotary feeder would be required.

The empirical research for bachelor's thesis was relatively brief, which resulted in the limited amounts of usable data. The research must be repeated further by doing additional building processes and having more powder going through the rotary feeder assembly. This should be done to ensure that there is adequate data to plot how much of the aluminium powder cold-welds on to the scraper plates in relation to the powder going through the rotary feeder assembly.

### 4.2 Future research recommendations

The distance between the wide scraper plates and the rotary feeder evidently affects the amount of cold-welded aluminium. The greater the distance, the smaller the amount of aluminium powder passing through. The optimal distance in how the dispensation of powder through the rotary feeder in relation to how much aluminium adheres, is subject for future research. If the distance is too long, too much powder is pouring through, possibly causing the powder to whirl. Respectively, if the gap is too small, the cold-welding phenomenon is greater.

Different scraper plate configuration variations should be studied to find the optimal gap width between the rotary feeder and the scraper plates. This could be done by testing with different configuration variations and comparing the results. Presumably the results may vary with different powders, alloys and particle sizes.

## References

[1] EOS M 400 - 3D Printing for Industrial Production. EOS GmbH n.d. https://www.eos.info/metal-solutions/metal-printers/eos-m-400 (accessed May 14, 2026).
[2] Yang X, Li R, Yuan T, Ke L, Bai J, Yang K. A comprehensive overview of additive manufacturing aluminum alloys: Classifications, structures, properties and defects elimination. Mater Sci Eng A 2025;919:147464. https://doi.org/10.1016/j.msea.2024.147464.
[3] Singh R, Gupta A, Tripathi O, Srivastava S, Singh B, Awasthi A, et al. Powder bed fusion process in additive manufacturing: An overview. Mater Today Proc 2020;26:3058–70. https://doi.org/10.1016/j.matpr.2020.02.635.
[4] Simola J. Instructions from expert (accessed May 15, 2026
[5] Ishfaq K, Abdullah M, Mahmood MA. A state-of-the-art direct metal laser sintering of Ti6Al4V and AlSi10Mg alloys: Surface roughness, tensile strength, fatigue strength and microstructure. Opt Laser Technol 2021;143:107366. https://doi.org/10.1016/j.optlastec.2021.107366.
[6] Frisk H. Aluminium. Svenskt Aluminium; p. 41.
[7] Aluminium for for Industrial 3D Printing | EOS. EOS GmbH n.d. https://www.eos.info/metal-solutions/metal-materials/aluminium (accessed May 14, 2026).
[8] Slip Systems in Crystals: FCC, BCC, and HCP Structures Explained | SAM n.d. https://www.samaterials.com/content/crystals-and-their-slip-systems.html (accessed May 14, 2026).
[9] Tajti F, Berczeli M, Weltsch Z. Optimizing adhesion in aluminum alloys: A cross-disciplinary approach to surface treatment and bond strength. Int J Adhes Adhes 2025;142:104068. https://doi.org/10.1016/j.ijadhadh.2025.104068.
[10] Friction Welding - an overview | ScienceDirect Topics n.d. https://www.sciencedirect.com/topics/materials-science/friction-welding (accessed May 15, 2026).
[11] Surface oxide and hydroxide effects on aluminum microparticle impact bonding. Acta Mater 2020;197:28–39. https://doi.org/10.1016/j.actamat.2020.07.011.
[12] Numerical prediction of the galling of aluminium alloys in cold strip drawing. J Manuf Process 2022;73:340–53. https://doi.org/10.1016/j.jmapro.2021.11.008.
[13] Deformation and cracking phenomena in cold sprayed 6061 Al alloy powders with nanoscale aluminum oxide films. Mater Sci Eng A 2022;841:143036. https://doi.org/10.1016/j.msea.2022.143036.
[14] Zhang H, Goltsberg R, Etsion I. Modeling Adhesive Wear in Asperity and Rough Surface Contacts: A Review. Materials 2022;15. https://doi.org/10.3390/ma15196855.
[15] Factors affecting wear and galling – British Stainless Steel Association n.d. https://bssa.org.uk/bssa_articles/factors-affecting-wear-and-galling/ (accessed May 14, 2026).
[16] Laieghi H, Kvvssn V, Butt MM, Ansari P, Salamci MU, Patterson AE, et al. Corrosion in laser powder bed fusion AlSi10Mg alloy. Eng Rep 2024;6:e12984. https://doi.org/10.1002/eng2.12984.

[17] Henry S, Minghetti T, Rappaz M. Dendrite growth morphologies in aluminium alloys. Acta Mater 1998;46:6431–43. https://doi.org/10.1016/S1359-6454(98)00308-5.
[18] Simola J. AlSi10Mg(Fe) painevalualumiinin lämmönjohtavuus. Master's Thesis. Tampereen teknillinen yliopisto, 2016.