

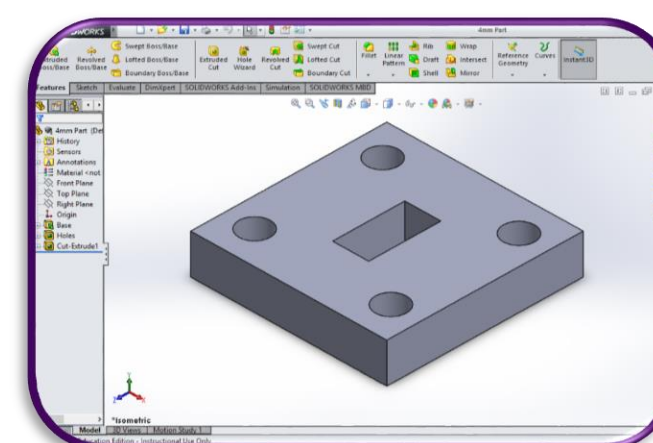
Research Highlights

- Selective Laser Melting(SLM)
- Support Structures
- Overhang
- Defects

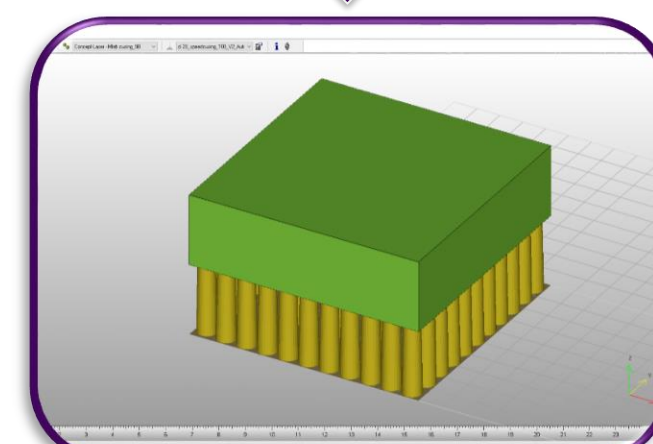
Experiment Objectives

- Examine the process of dross formation and identify the related impact to the quality of SLM printed parts.
- Study any correlation between support distance and dross formation in SLM printed parts.
- Determine a proper support distance to prevent significant damage and dross formation in the future.

Printing Procedures



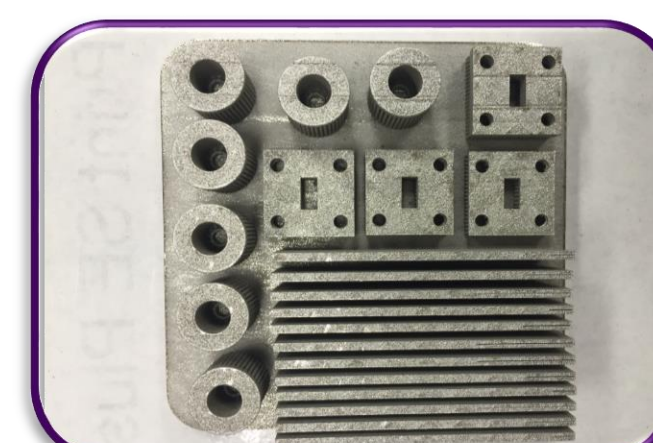
- 3D metal/alloy parts are designed using the CAD software *Solidworks*
- A 19x19x4 mm specimen is selected for this experiment.



- Support structures are generated using the *Autofab Mlab* package
- Cone shaped supports are 4.0mm in height and have a diameter of 0.7 mm at the plane in contact with the part and a diameter of 0.8mm in contact with the building platform



- *Conceptlaser Mlab-cusing-R* SLM system used for the printing process.
- High-powered laser selectively melts stainless steel 316 powders layer by layer in a closed environment.



- Build platform is removed and cleaned of any remaining metallic powders
- Supports are manually removed

Introduction

Selective Laser Melting (SLM) is a key Additive Manufacturing (AM) technology capable of producing complex 3D metallic parts with a wide range of applicability. A major challenge in SLM is dross formation in overhang regions which causes reduced dimensional accuracy and introduces defects. In real applications, overhanging structures cannot always be avoided. Therefore, it is essential to understand dross formation mechanisms and to identify the related impact to SLM printed parts.

Results

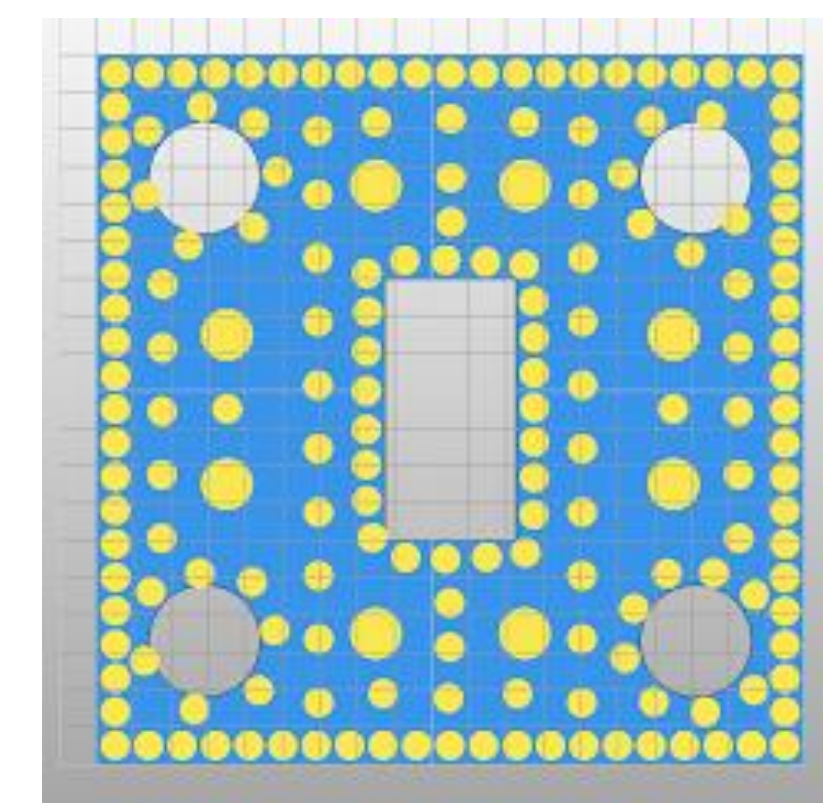


Fig. 1 Autofab generated support structure, modified 4x4mm XY Grid

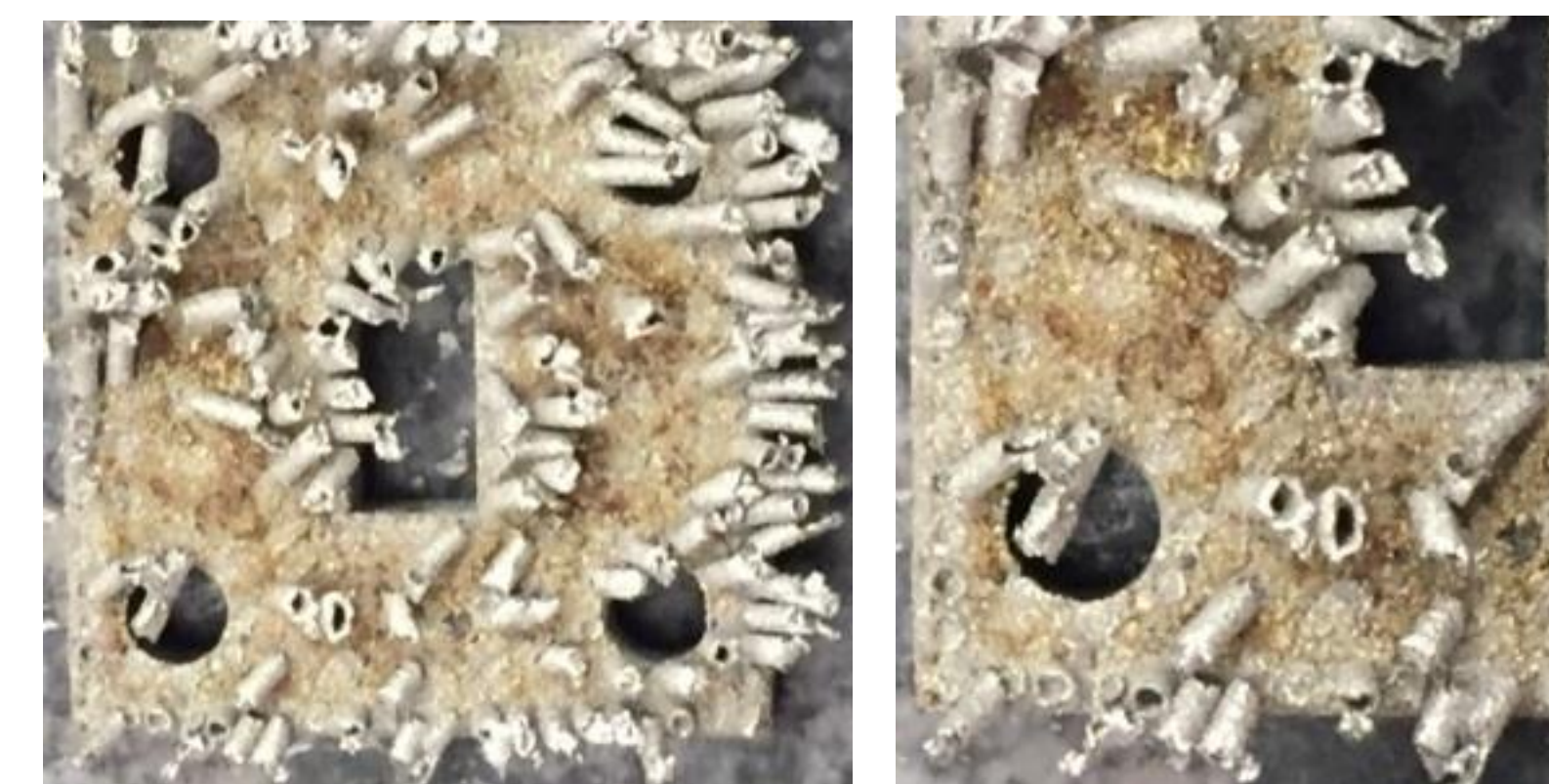


Fig.2 Dross formation in the overhang regions (the yellowish color regions)

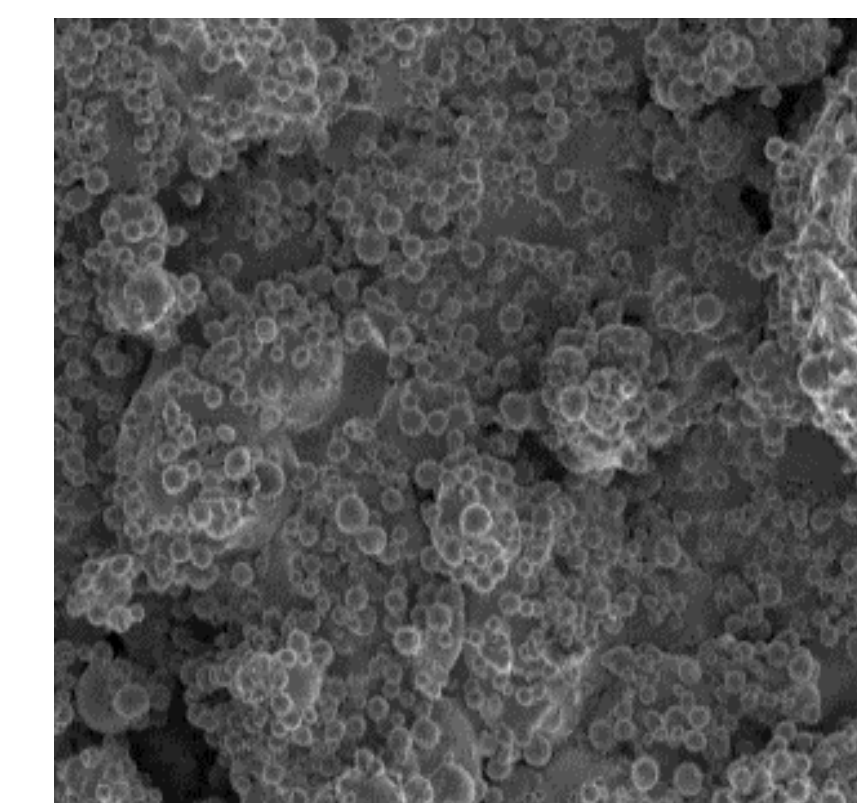


Fig.3 SEM image showing dross formation

- The correlation between unsupported areas in Fig.1 and development of yellowish color in Fig.2 indicate dross formation in these overhang regions.
- **Dross formation is directly related to the size of the unsupported areas**, where a large gap leads to a more pronounced discoloration and a poorer definition of the targeted geometry.
- SEM imaging, Fig.3, illustrates the uneven surface where dross formation occurred. It is apparent that the porous powder bed provides a capillary suction to the molten pool. The melt pool spreads and permeates unevenly into the powder bed and many powders stick to the surface due to partial melting.

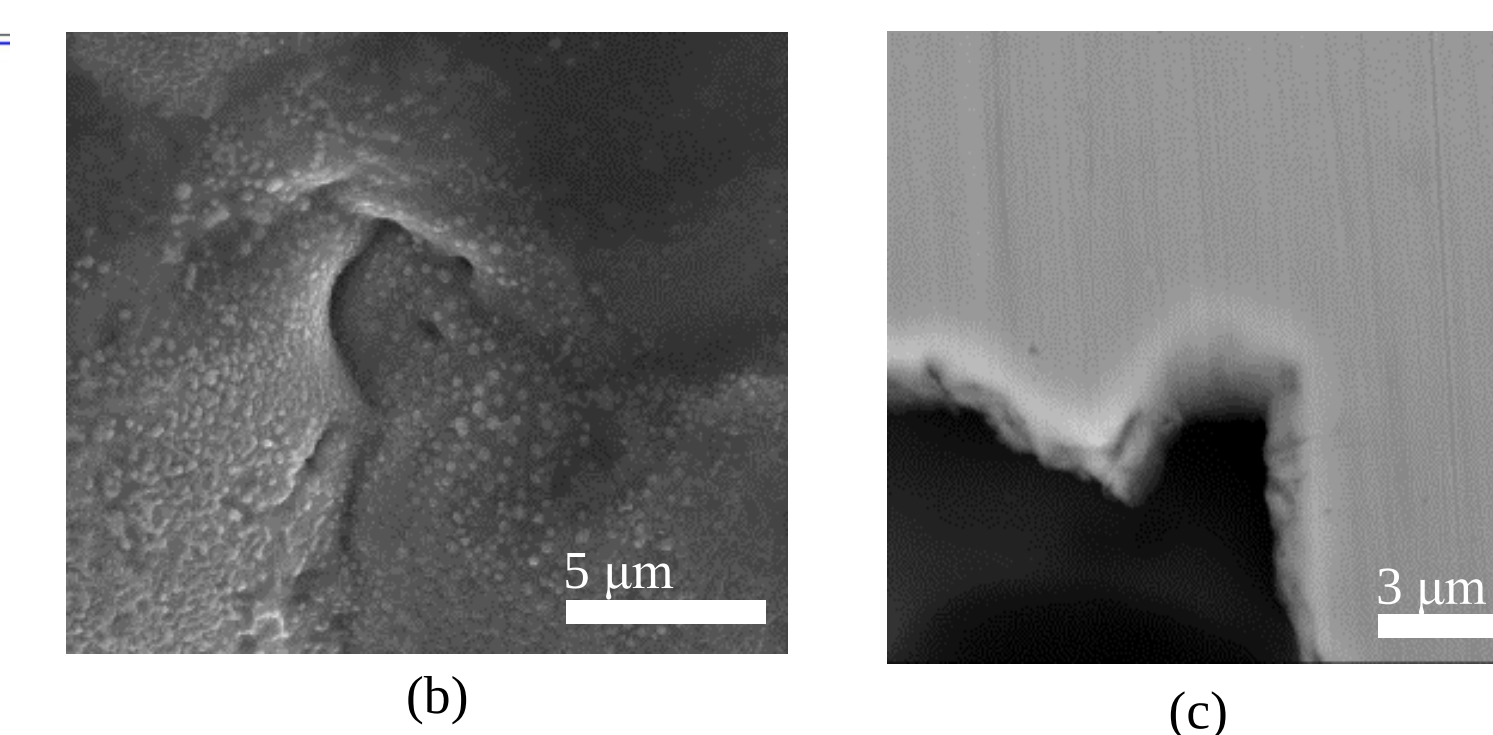
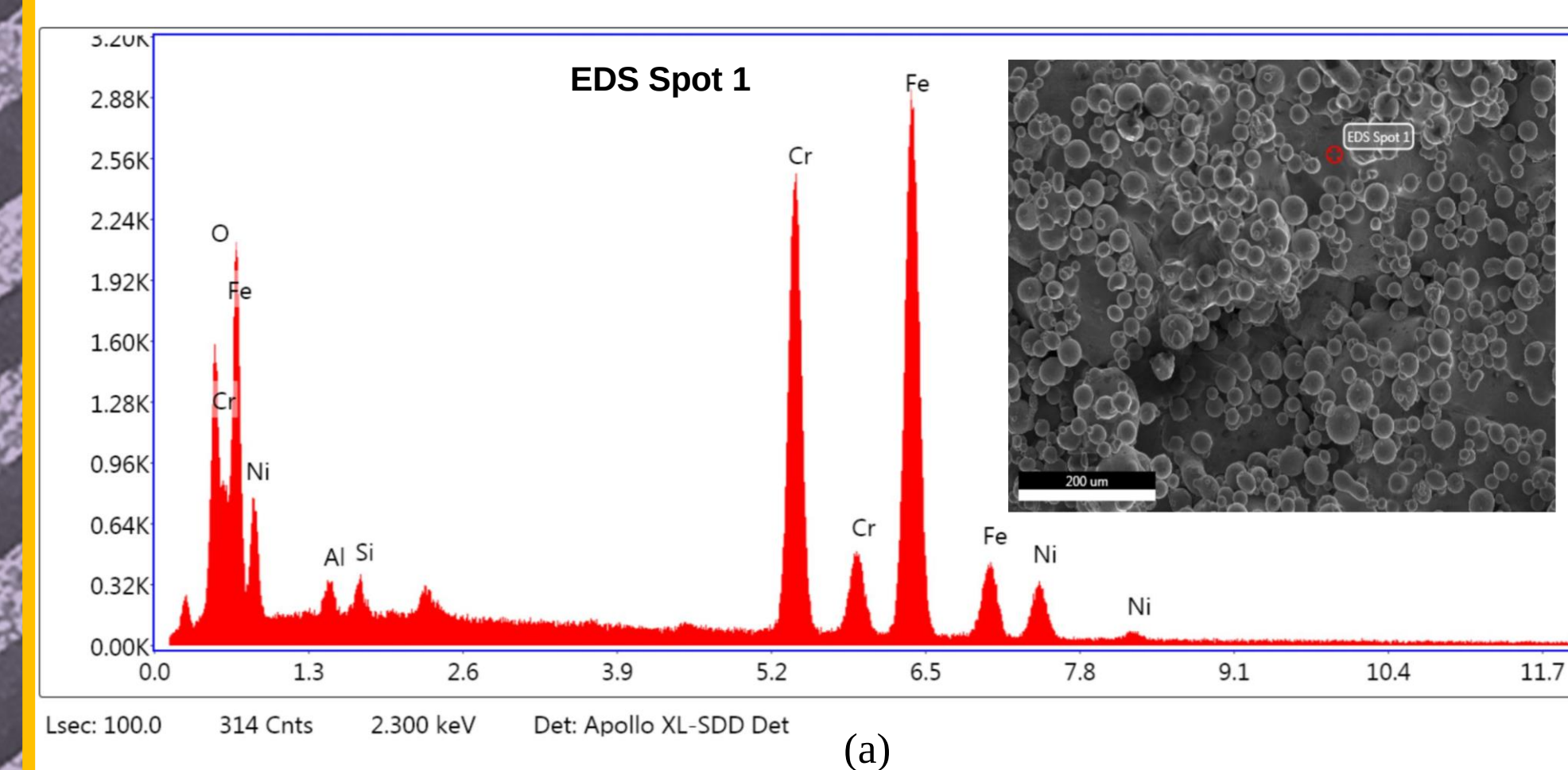


Fig.4 (a): EDS showing high oxygen level, around atomic 19%, on the dross surface; (b) formation of nano-sized particles; (c) the cross-section showing a thin oxide layer.

The elemental compositions on the surface of the dross region were determined by EDS scans, Fig.4. Although the *Conceptlaser Mlab-cusing-R* SLM system maintains an oxygen level of only around 0.3% in the processing chamber, the **dross region has a very high oxygen level**. Based on the measurements, Fig. 4, the oxygen level on the surface of dross is as high as 19%. Many nano-sized particles on the dross surface indicate a vapor condensation process, Fig.4 (b). The cross-section SEM image, Fig.4 (c), reveals the major impact of dross formation is poor geometrical replication. Although the oxidation layer is rough, the thickness is actually quite small.

An additional experiment using five 10x10x3mm squares was conducted to illustrate the correlation between support distance and dross formation. **As the support distance increased, the dross formation became increasingly more noticeable** with darker coloration as well as the introduction of numerous defects. Further test will be conducted on these specimens to examine oxygen concentration within each sample.

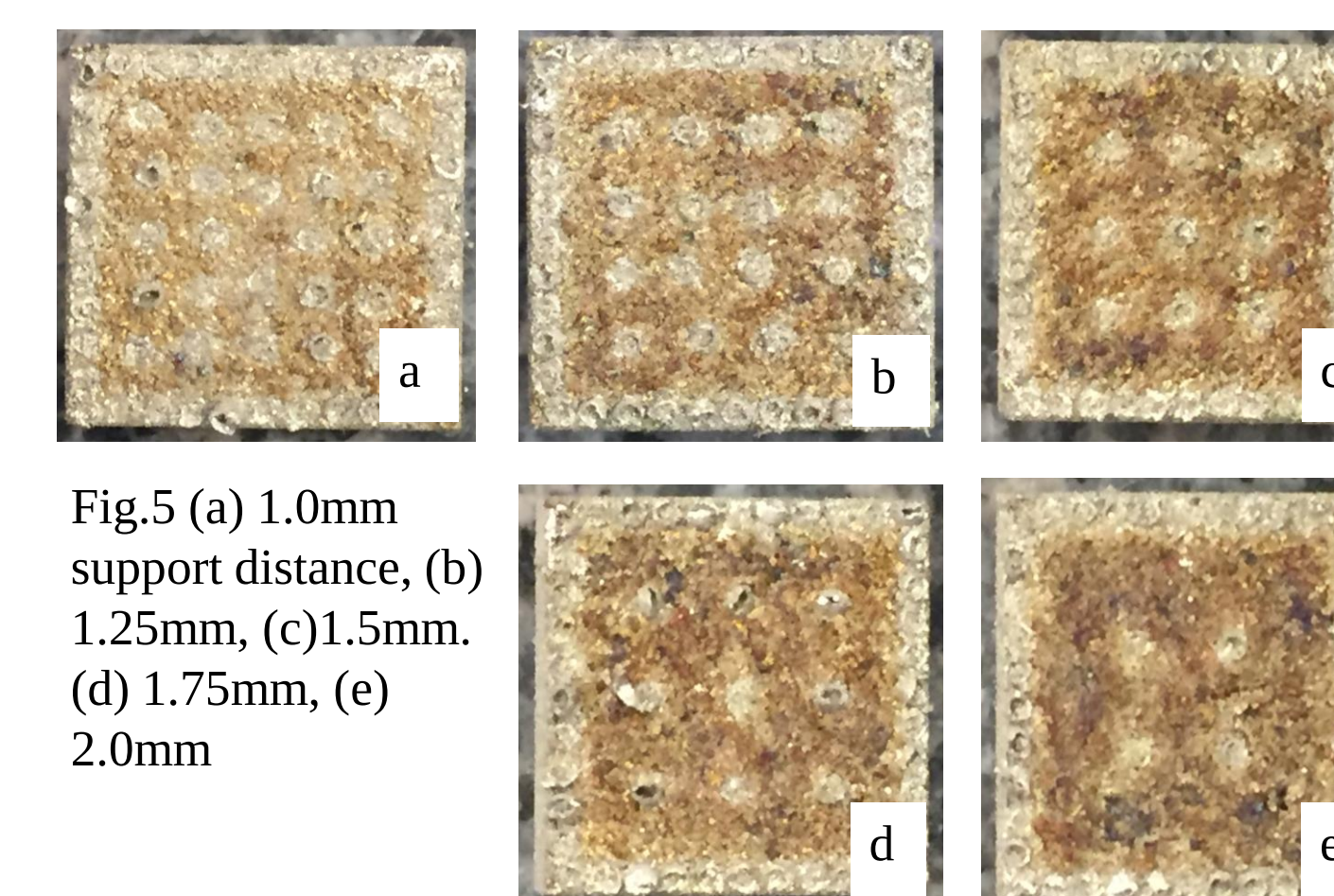


Fig.5 (a) 1.0mm support distance, (b) 1.25mm, (c) 1.5mm, (d) 1.75mm, (e) 2.0mm

Discussion

Even though the **oxygen level** within the build chamber is **limited to 0.3%** through a closed-loop control, **extremely high temperatures** from the laser rapidly **increase oxidation rates**. For the fully supported regions, solidified structures underneath the powder layer conduct and absorb a significant amount of heat emitted from the laser; however, for overhang regions, the low heat conduction rate and deep penetration of the laser provide the necessary environment for vaporization within the powder bed. During the printing process, dark colored fumes were observed originating from the powder bed, specifically during the printing of overhang regions of the specimen. These fumes, composed of minute metal particles, have a tendency of reacting with residual oxygen to form metal oxides. Because of the deep penetration of the laser in overhang regions, some of these oxides are trapped in the dross.

The **distance** between the supporting structures can **greatly influence dross formation** as well. Compared to a 10mm diameter, 3mm height circular disk, Fig.5, printed in a previous experiment, the dross formation of the square specimen, Fig.6, is much less intense. The support structures used for both specimens were 4mm in length and of identical dimensions. The only difference was the increased distance between support structures for the circular disk as well as a lack of supports around the outer edge of the specimen. Based on observations from the five 10x10x3mm squares, **significant dross formation** and defects began to occur with **support distances 1.25mm or greater**.



Fig.5 Less optimized support



Fig.6 Better supports

Conclusions

- Under EDS scans, it is shown that **dross areas have high concentrations of oxygen** due to reactions between the residual oxygen and the vaporized metal powders under laser heating.
- Due to the lack of solidified structures underneath to absorb and reflect that heat in the overhang regions, **vaporization of metal powders occurs deep inside the powder bed** and a portion of oxidation products is trapped within the dross surface causing poor geometrical replication.
- The distance of the supporting structures, especially around the edge of the specimens, can greatly influence the dross formation. The gap between the support structures should be **limited to around 1 mm** to prevent damage.

Acknowledgements

Supported by the National Science Foundation through cooperative agreement OIA-1541079 and the Louisiana Board of Regents.