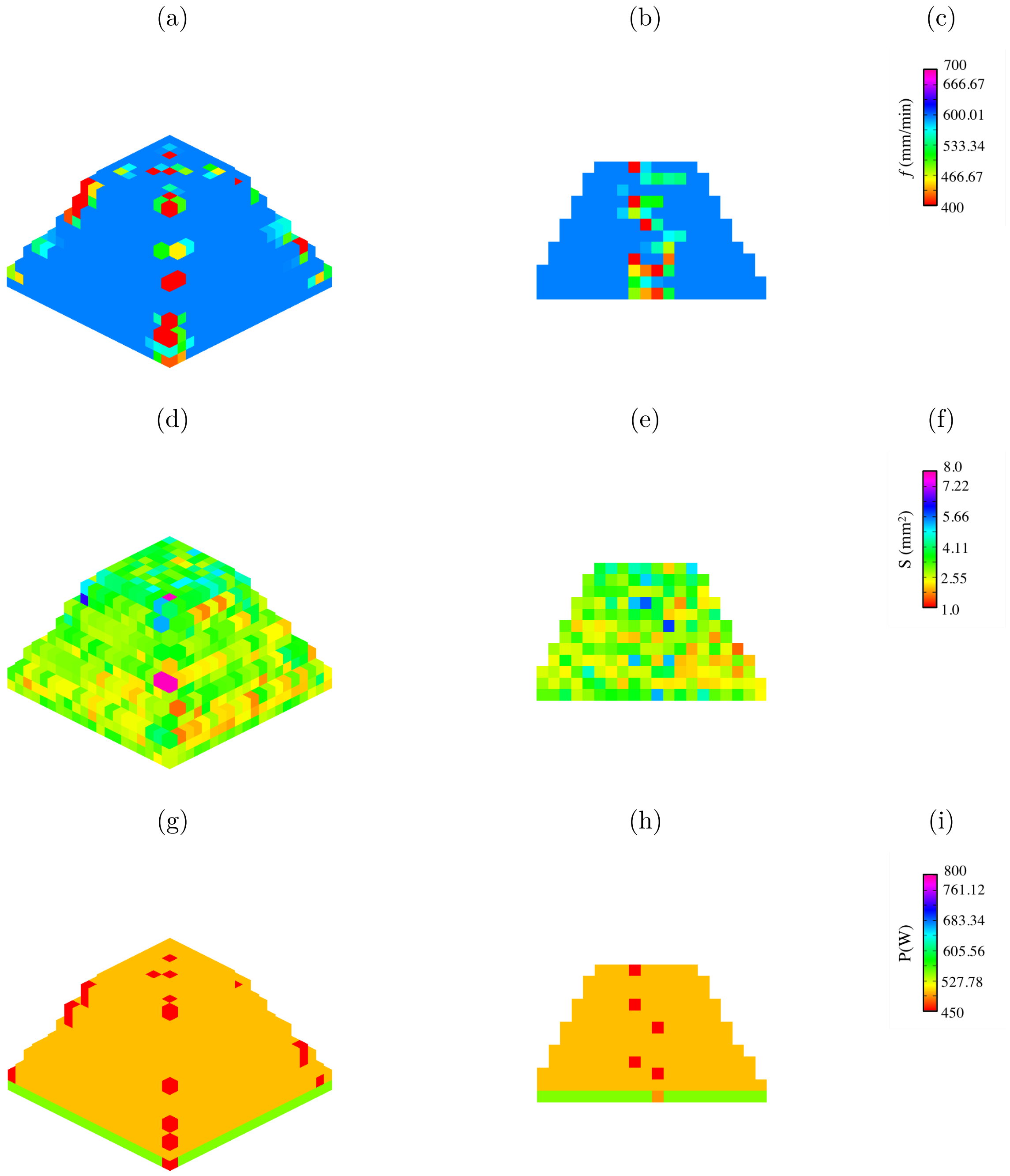
APPENDIX

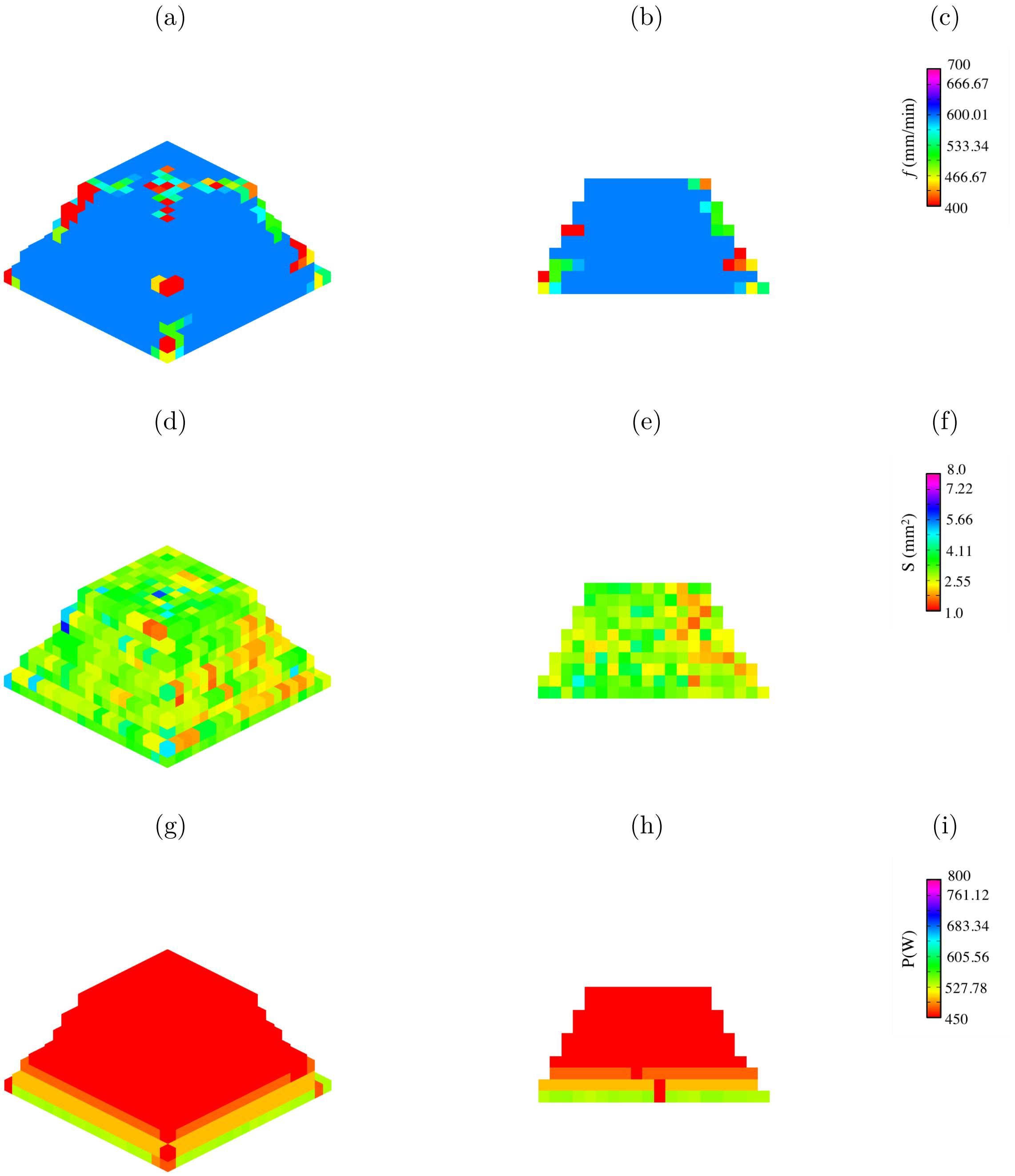
APPENDIX A – DTMAP3D PLOTS: PYRAMID

Figure 63 – DTMap3D plots for set pyramid building contour strategy at 500 W laser power: feed speed in (a) isometric view, (b) xz-plane ($y = 10$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 10$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 10$), and (i) Laser power scale.



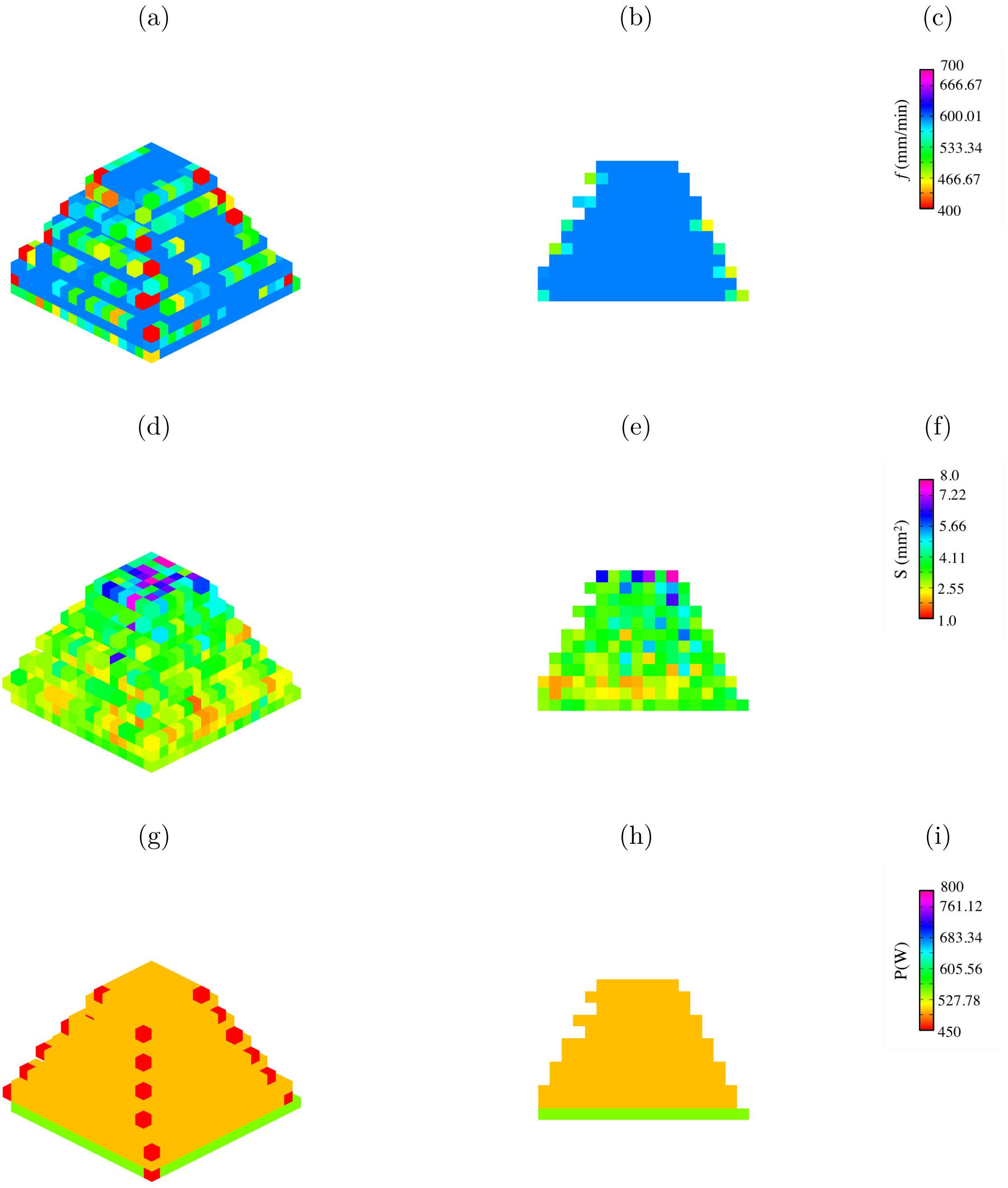
Source: Author

Figure 64 – DTMap3D plots for set pyramid building contour strategy at 550 W to 450 W laser power gradient: feed speed in (a) isometric view, (b) xz-plane ($y = 10$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 10$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 10$), and (i) Laser power scale.



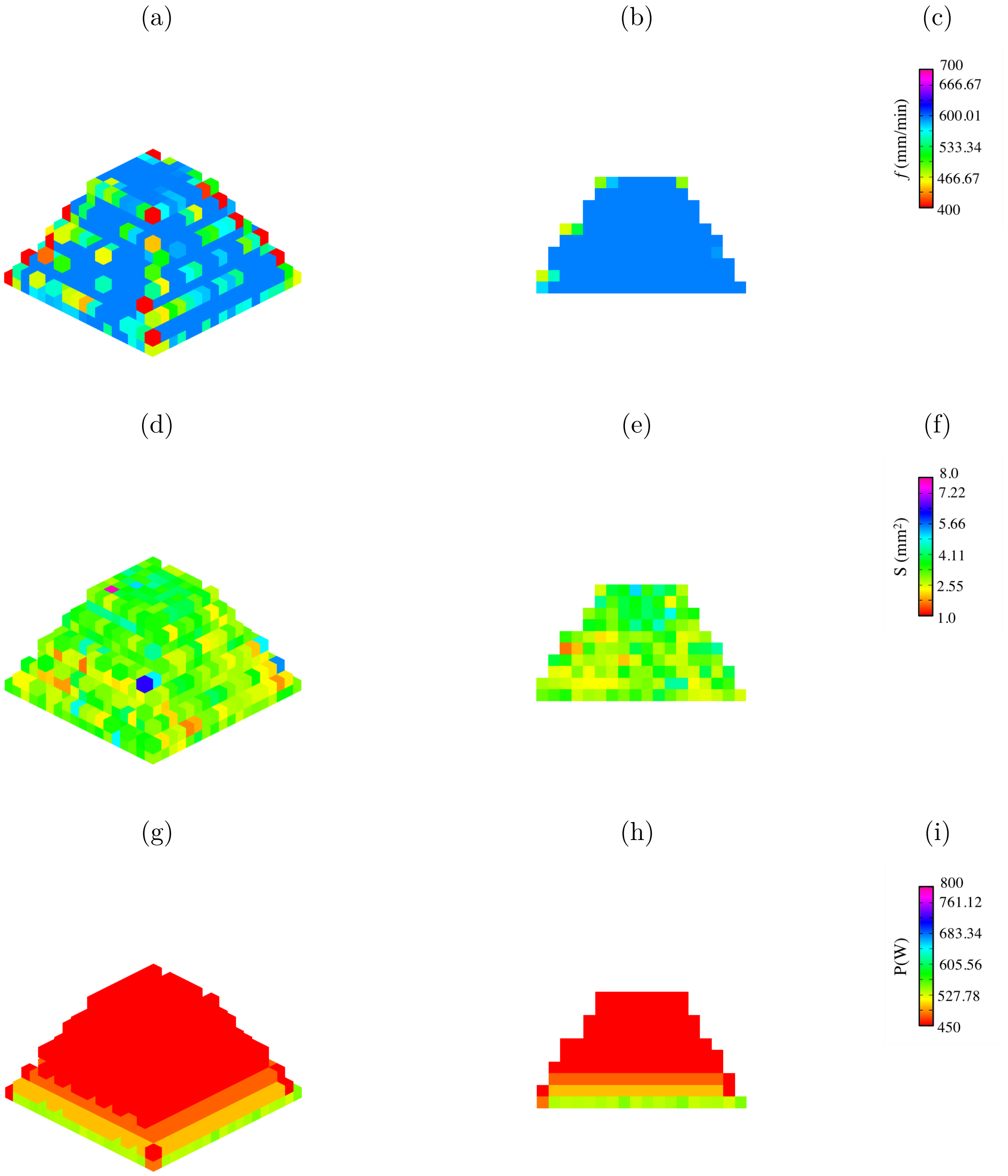
Source: Author

Figure 65 – DTMap3D plots for set pyramid building zigzag strategy at 500 W laser power: feed speed in (a) isometric view, (b) xz-plane ($y = 10$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 10$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 10$), and (i) Laser power scale.


(a) (b) (c)
(d) (e) (f)
(g) (h) (i)

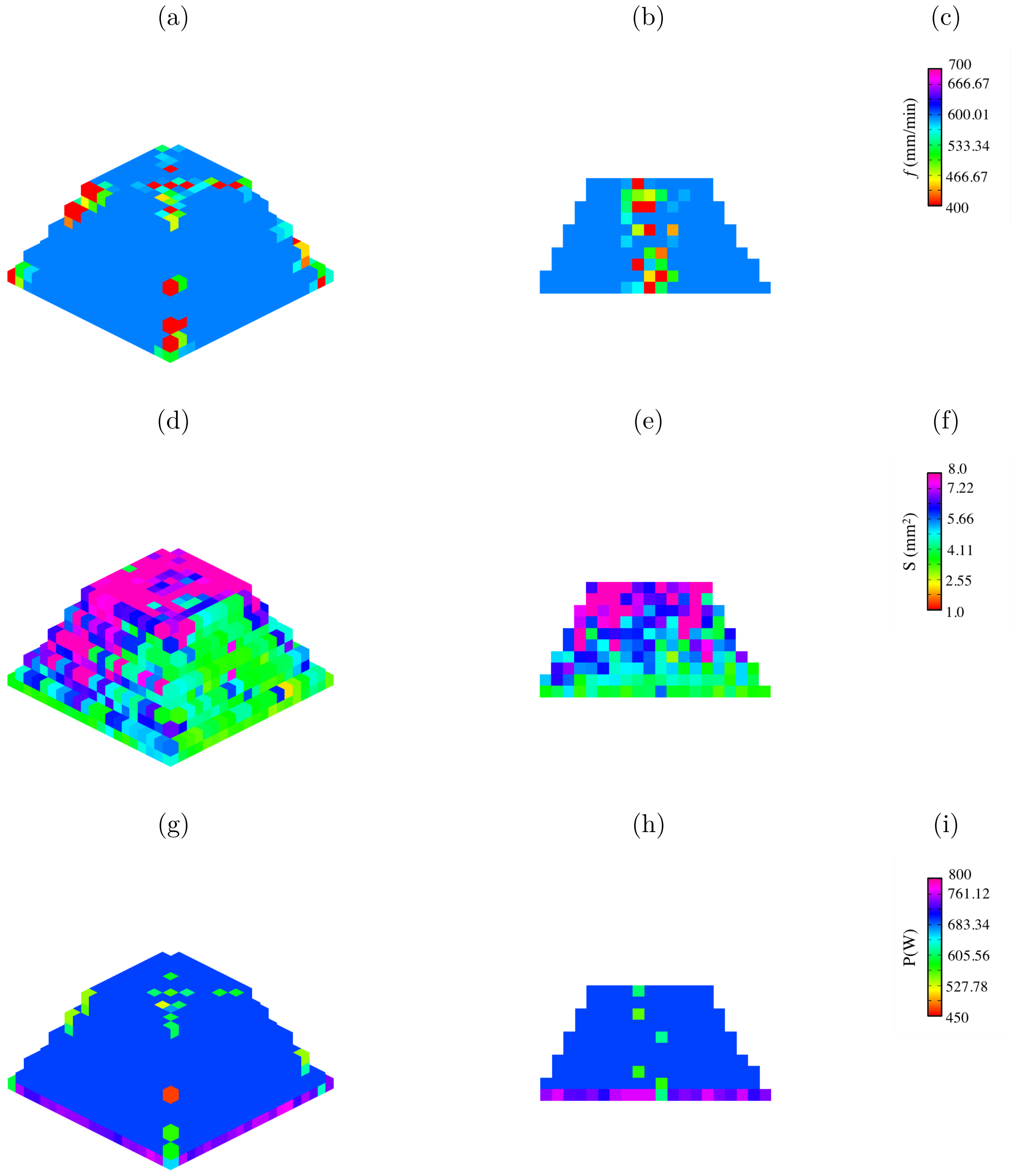
Source: Author

Figure 66 – DTMap3D plots for set pyramid building zigzag strategy at 550 W to 450 W laser power gradient: feed speed in (a) isometric view, (b) xz-plane ($y = 10$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 10$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 10$), and (i) Laser power scale.



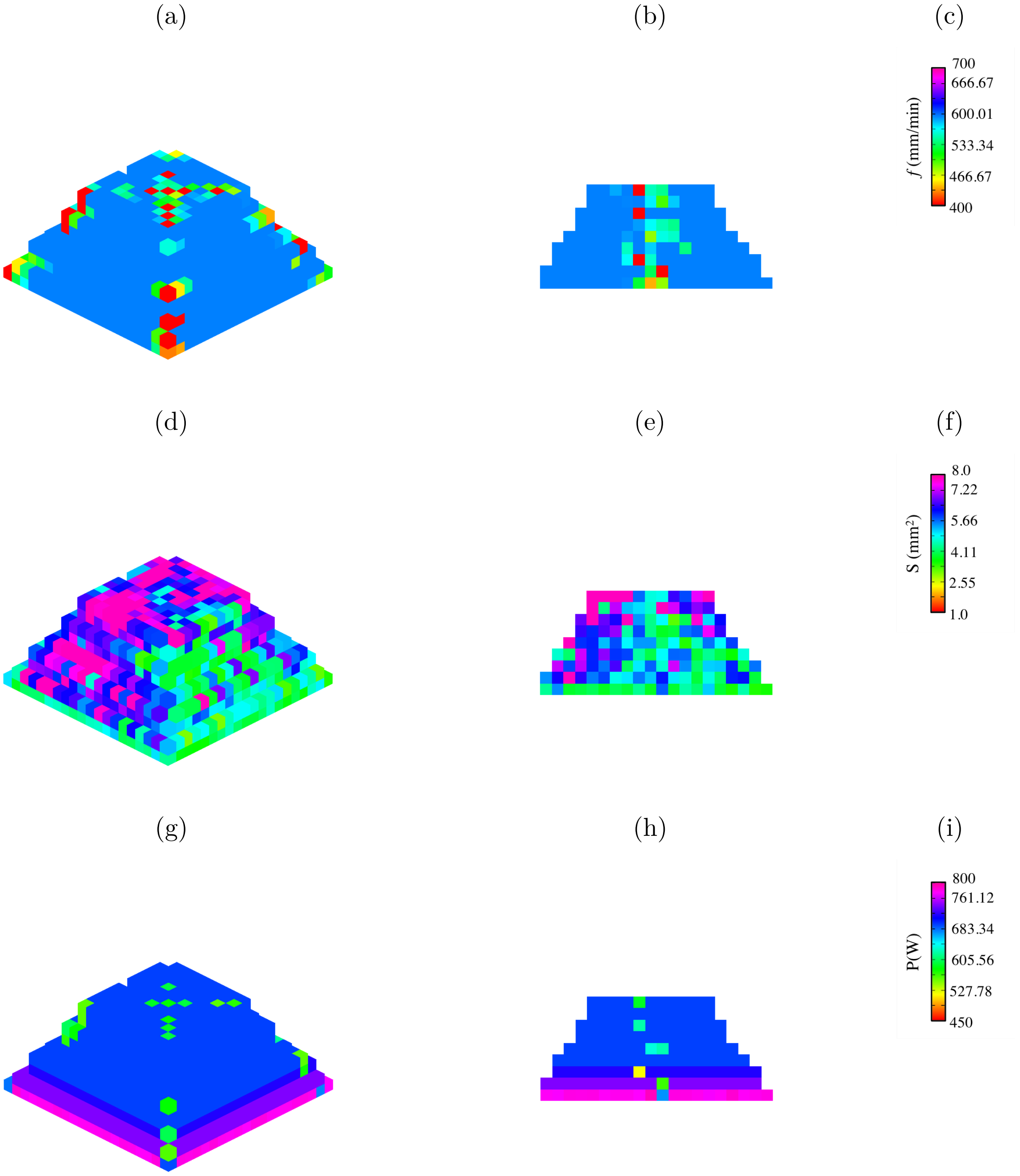
Source: Author

Figure 67 – DTMap3D plots for set pyramid building contour strategy at 700 *W* laser power: feed speed in (a) isometric view, (b) xz-plane ($y = 10$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 10$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 10$), and (i) Laser power scale.



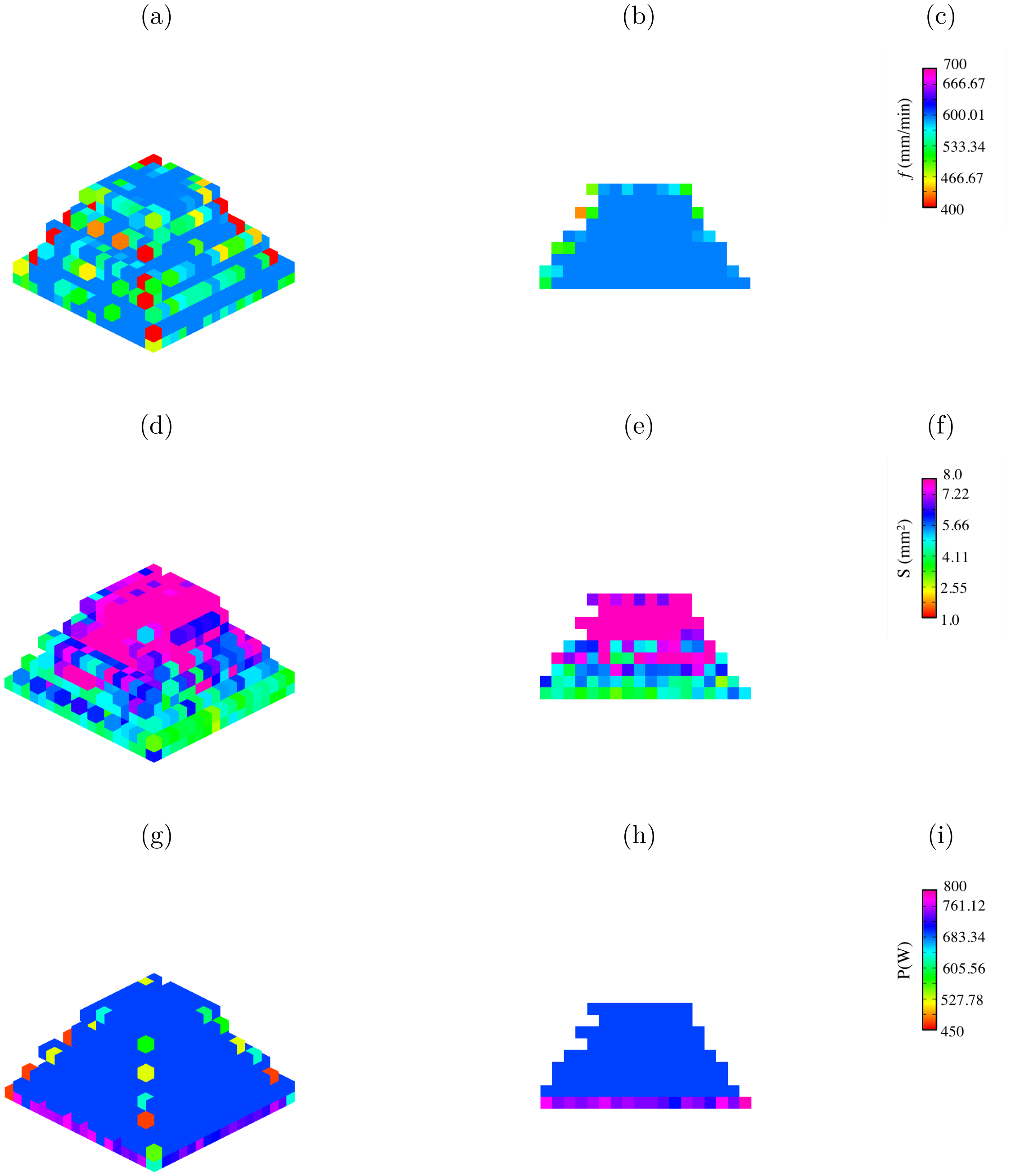
Source: Author

Figure 68 – DTMap3D plots for set pyramid building contour strategy at 800 W to 700 W laser power gradient: feed speed in (a) isometric view, (b) xz-plane ($y = 10$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 10$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 10$), and (i) Laser power scale.



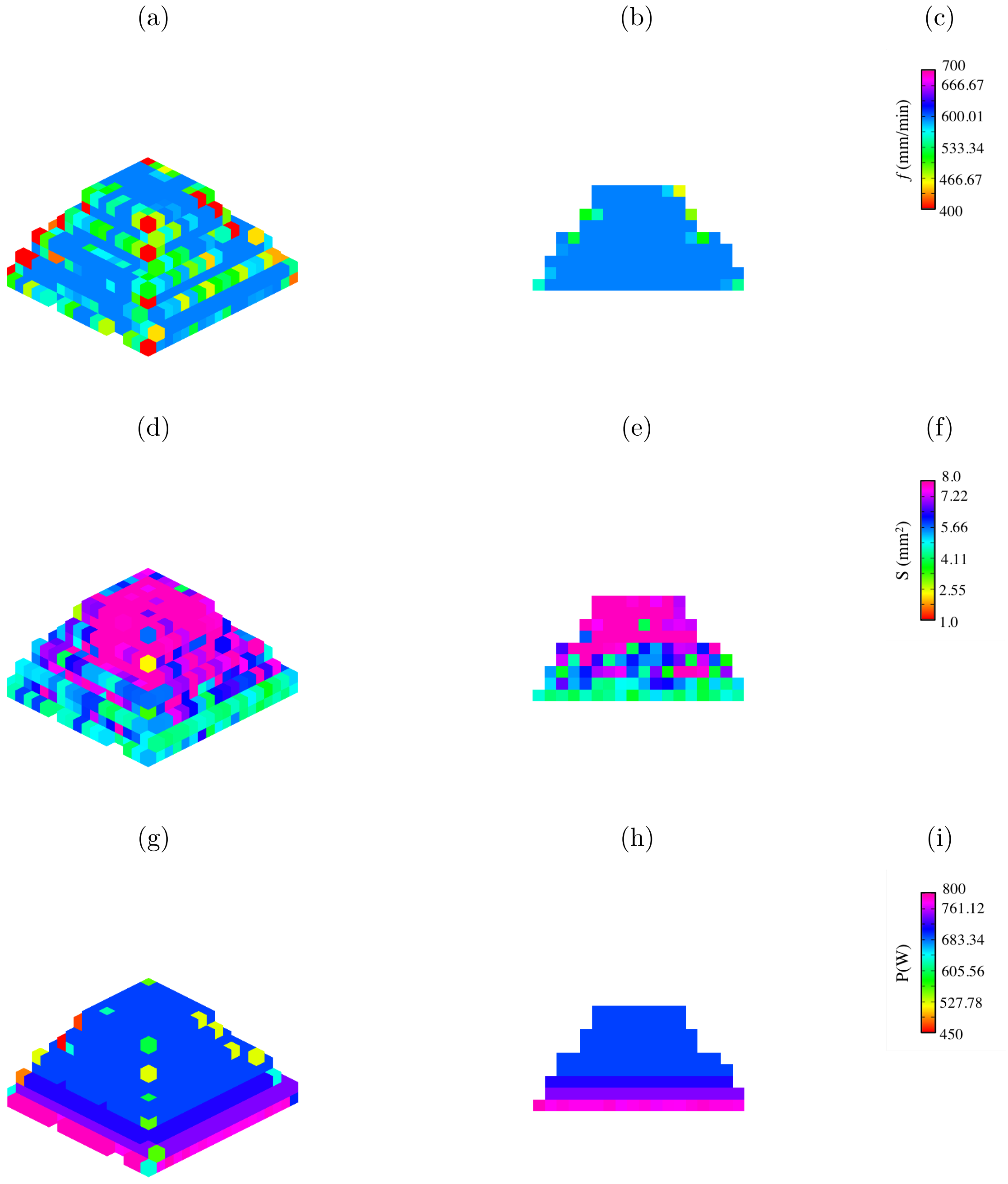
Source: Author

Figure 69 – DTMap3D plots for set pyramid building zigzag strategy at 700 W laser power: feed speed in (a) isometric view, (b) xz-plane ($y = 10$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 10$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 10$), and (i) Laser power scale.


(a) (b) (c)
(d) (e) (f)
(g) (h) (i)

Source: Author

Figure 70 – DTMap3D plots for set pyramid building zigzag strategy at 800 W to 700 W laser power gradient: feed speed in (a) isometric view, (b) xz-plane ($y = 10$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 10$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 10$), and (i) Laser power scale.



(a) (b) (c)

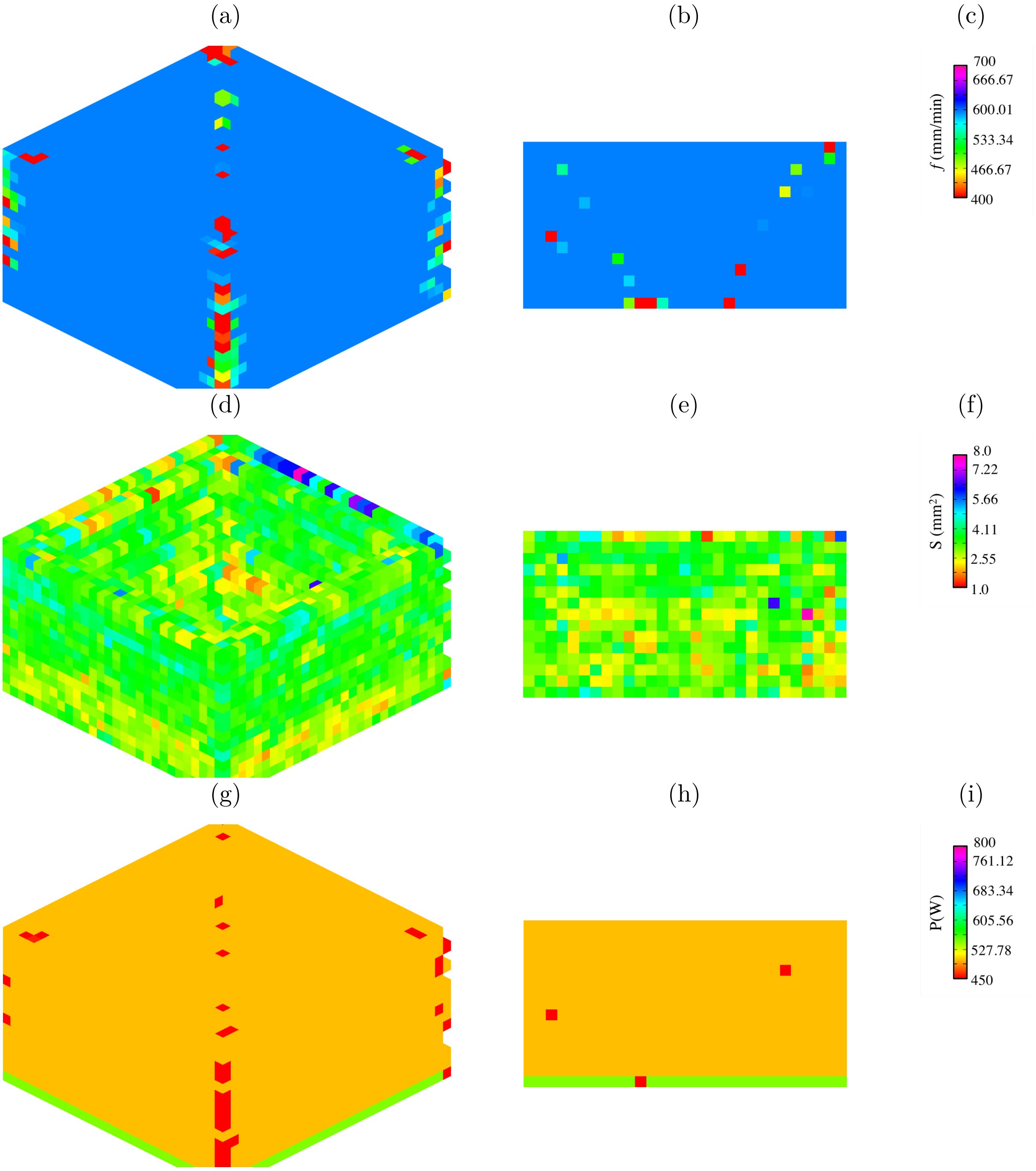
(d) (e) (f)

(g) (h) (i)

Source: Author

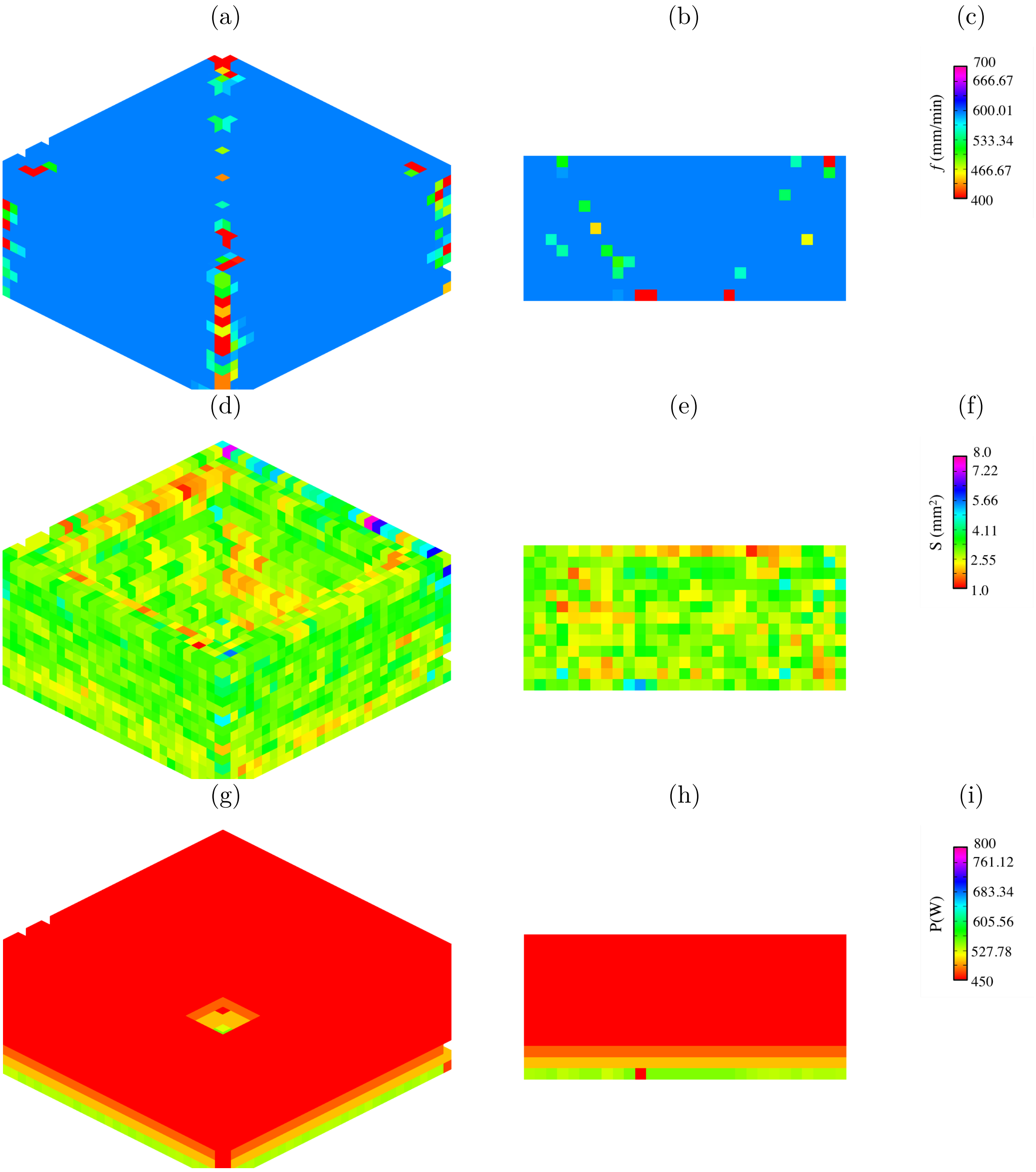
APPENDIX B – DTMAP3D PLOTS: PYRAMID MOULD

Figure 71 – DTMap3D plots for set pyramid mould building contour strategy at 500 W laser power: feed speed in (a) isometric view, (b) xz-plane ($y = 13$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 13$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 13$), and (i) Laser power scale.



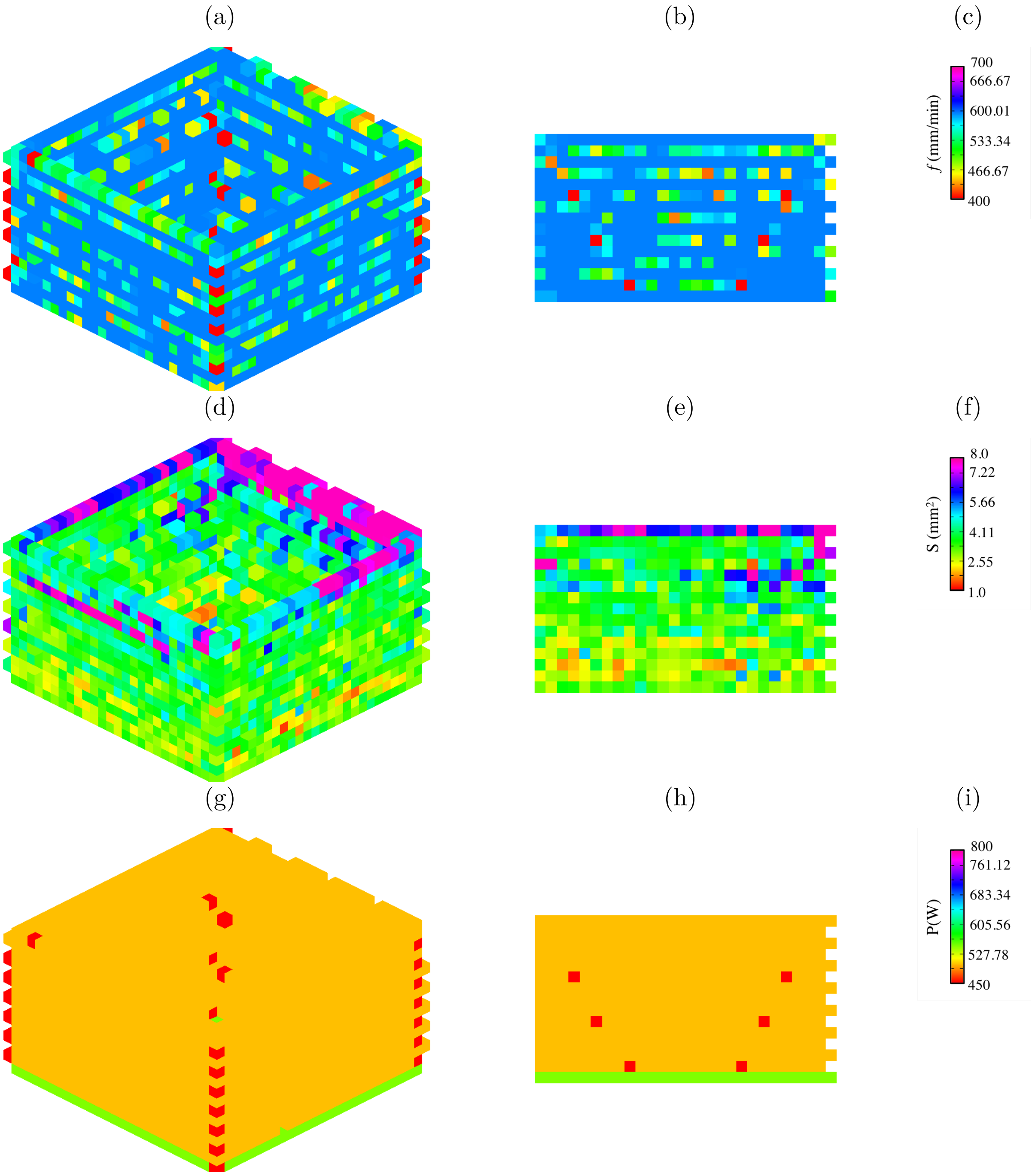
Source: Author

Figure 72 – DTMap3D plots for set pyramid mould building contour strategy at 550 W to 450 W laser power gradient: feed speed in (a) isometric view, (b) xz-plane ($y = 13$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 13$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 13$), and (i) Laser power scale.



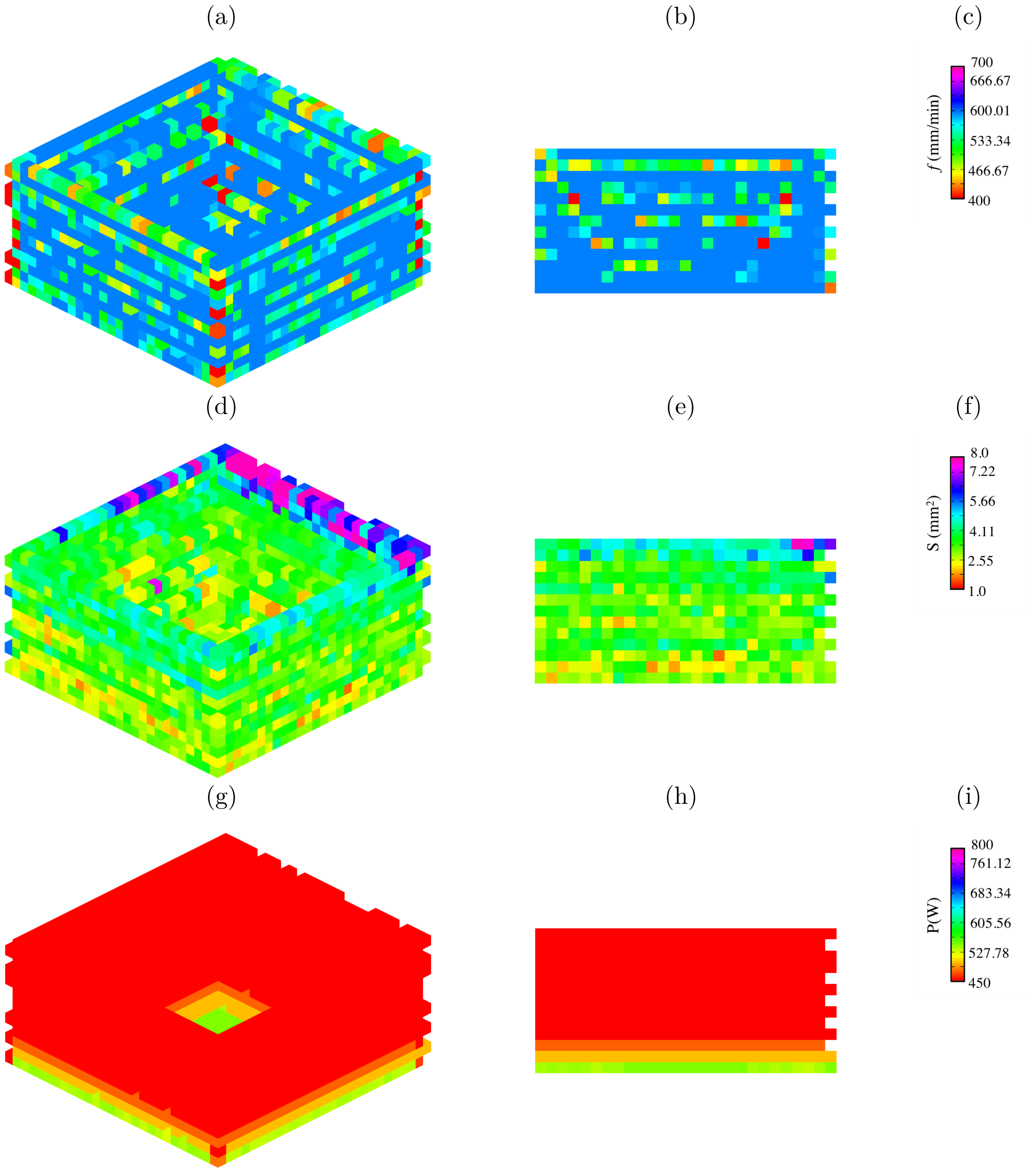
Source: Author

Figure 73 – DTMap3D plots for set pyramid mould building zigzag strategy at 500 W laser power: feed speed in (a) isometric view, (b) xz-plane ($y = 13$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 13$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 13$), and (i) Laser power scale.



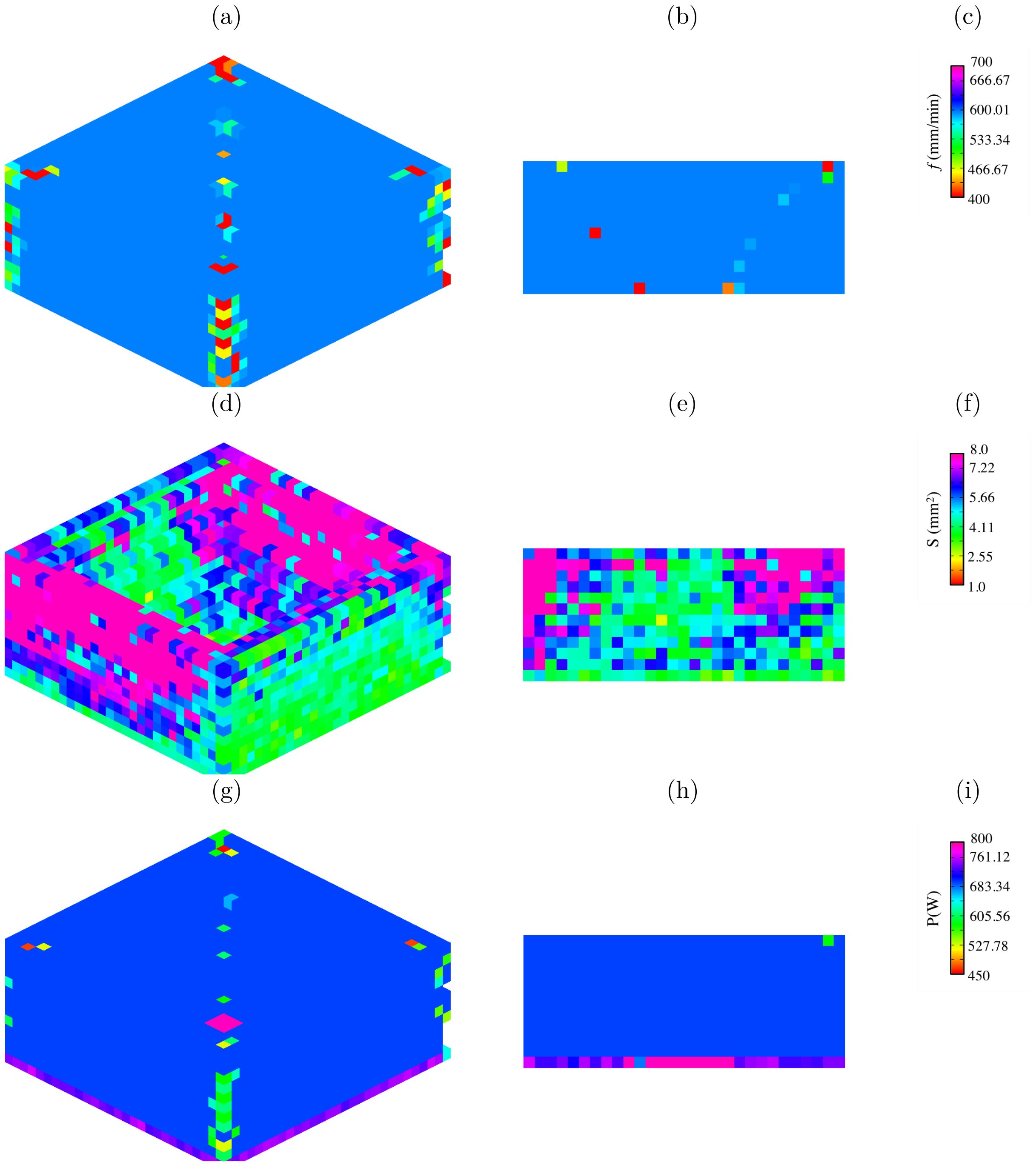
Source: Author

Figure 74 – DTMap3D plots for set pyramid mould building zigzag strategy at 550 *W* to 450 *W* laser power gradient: feed speed in (a) isometric view, (b) xz-plane ($y = 13$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 13$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 13$), and (i) Laser power scale.



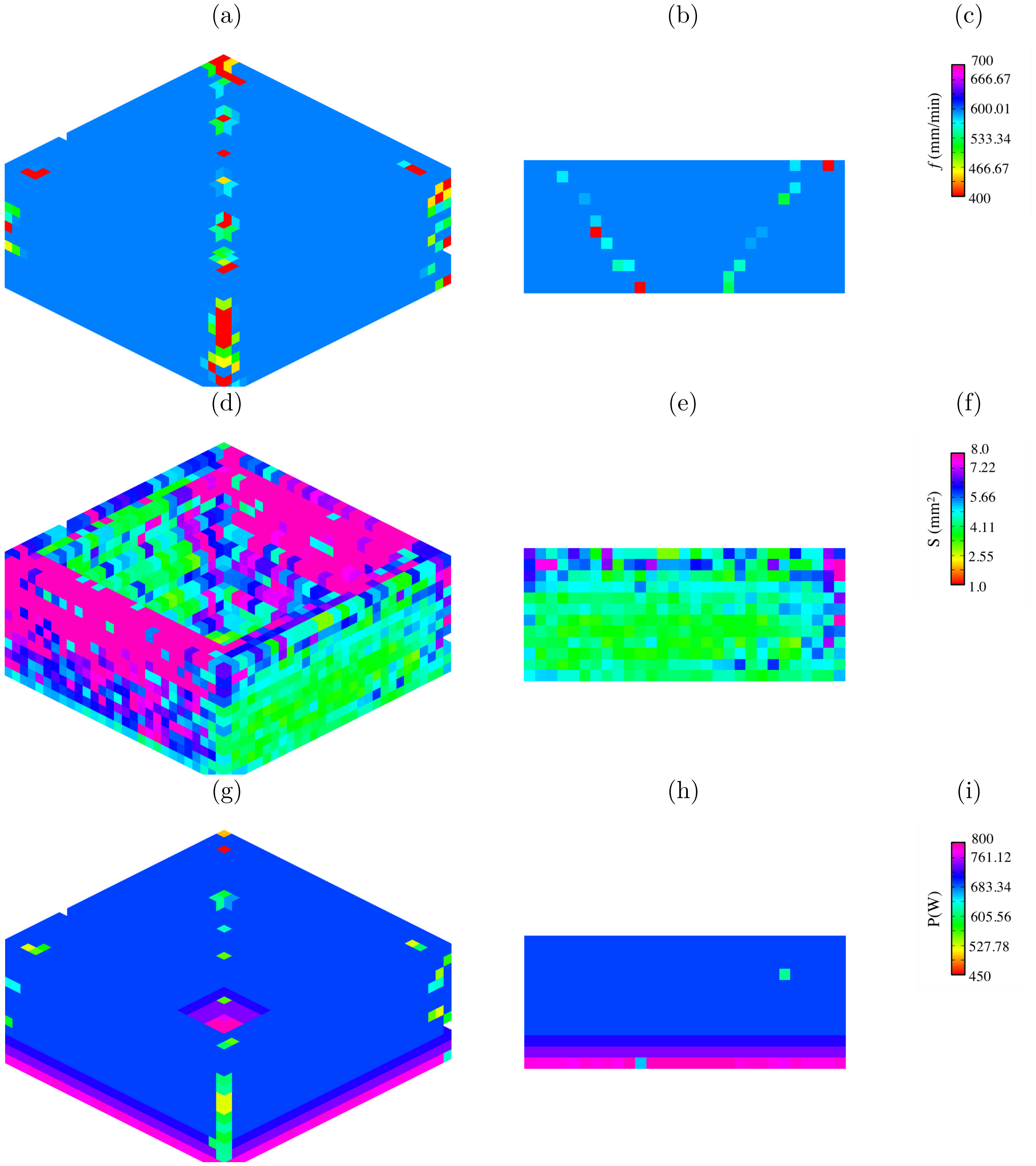
Source: Author

Figure 75 – DTMap3D plots for set pyramid mould building contour strategy at 700 W laser power: feed speed in (a) isometric view, (b) xz-plane ($y = 13$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 13$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 13$), and (i) Laser power scale.



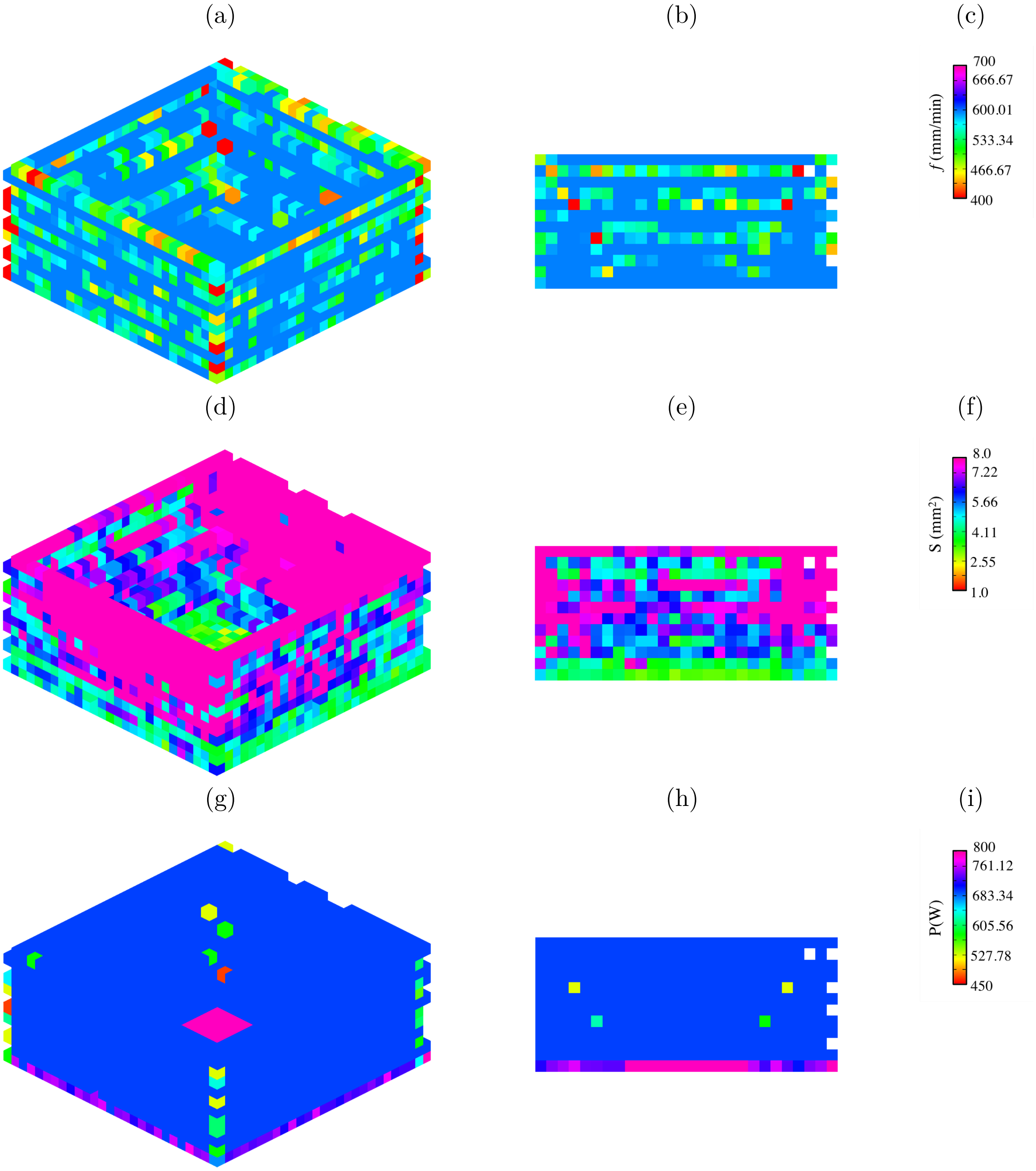
Source: Author

Figure 76 – DTMap3D plots for set pyramid mould building contour strategy at 800 W to 700 W laser power gradient: feed speed in (a) isometric view, (b) xz-plane ($y = 13$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 13$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 13$), and (i) Laser power scale.



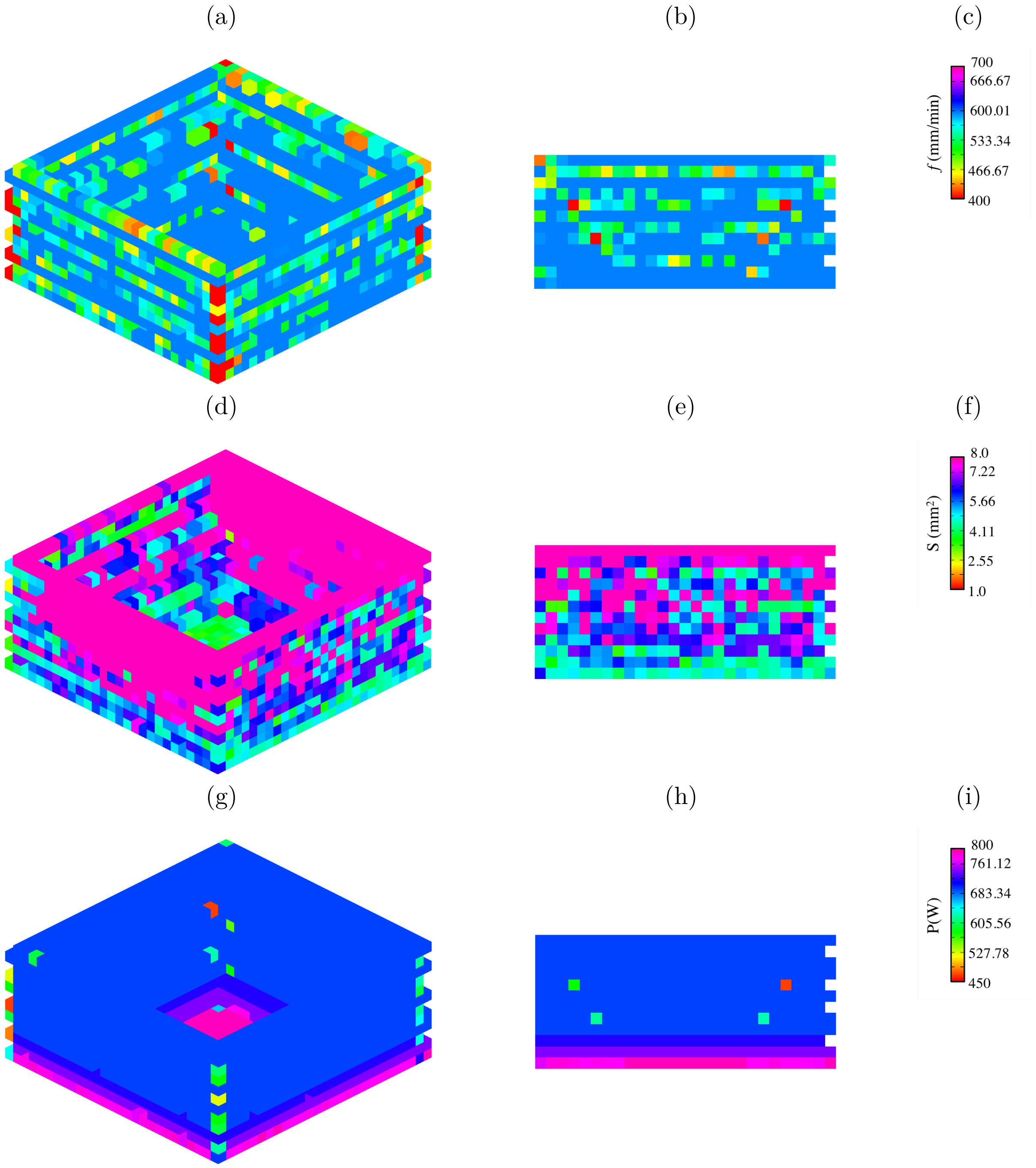
Source: Author

Figure 77 – DTMap3D plots for set pyramid mould building zigzag strategy at 700 *W* laser power: feed speed in (a) isometric view, (b) xz-plane ($y = 13$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 13$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 13$), and (i) Laser power scale.



Source: Author

Figure 78 – DTMap3D plots for set pyramid mould building zigzag strategy at 800 *W* to 700 *W* laser power gradient: feed speed in (a) isometric view, (b) xz-plane ($y = 13$), and (c) feed scale; spot area in (d) isometric view, (e) xz-plane ($y = 13$), and (f) Spot area scale; and laser power in (g) isometric view, (h) xz-plane ($y = 13$), and (i) Laser power scale.



Source: Author

ANNEX

ANNEX A – PUBLICATIONS

Progress in Additive Manufacturing
https://doi.org/10.1007/s40964-022-00325-3

REVIEW ARTICLE

Abrasive and non-conventional post-processing techniques to improve surface finish of additively manufactured metals: a review

Déborah De Oliveira[1] · Milla Caroline Gomes[2] · Aline Gonçalves Dos Santos[3] · Kandice Suane Barros Ribeiro[4] · Iago José Vasques[4] · Reginaldo Teixeira Coelho[4] · Marcio Bacci Da Silva[2] · Nguyen Wayne Hung[5]

Received: 25 February 2022 / Accepted: 1 July 2022

Abstract

Metal additive manufacturing (MAM) has attracted global industry and academia due to its flexibility and ability to achieve complex geometry. The inherent rough surfaces are of concerns and need to be addressed to meet the strict requirement of critical engineering components. This paper reviews the working principles for common MAM processes and summarizes current post-processing techniques for surface finish improvement. Relevant finishing techniques using abrasives and non-conventional techniques, such as grinding, polishing, laser, peening, buffing, and electrochemical polishing are reviewed, and typical results are documented for different AM processes. Limitation of each process and enhancing techniques using magnetism, ultrasonic, and pulsed current for selected processes are presented. Post processing not only reduces surface roughness, but also contributes to dimensional and form tolerances, and prolongs long-term fatigue and creep life of AM metals. Although post-processing techniques can effectively remove surface defects to achieve submicron surface finish, controlling of surface defects that extend deeply below a surface is still a challenge. Future hybrid system that combines AM and a non-traditional post-process would meet the requirement for MAM.

Keyword Metallic additive manufacturing · Finishing · Polishing · Surface quality · Abrasive finishing · Non-traditional processes

Abbreviations

AM	Additive manufacturing
AFM	Abrasive flow machining
ASTM	American Society for Testing and Materials
BJ	Binder jetting
CAD	Computer-aided design
CBN	Cubic boron nitride
CNC	Computer numerical control
CNT	Carbon nanotubes
CSAM	Cold spray additive manufacturing
CSAM	Cold spray additive manufacturing
DED	Directed energy deposition
DMD	Direct metal deposition
DMLS	Direct metal laser sintering
EBFFF	Electron beam free form fabrication
EBM	Electron beam melting
ECDe	Electrochemical deburring
ECF	Electrochemical finishing
ECG	Electrochemical grinding
ECH	Electrochemical honing
ECM	Electrochemical machining
ECP	Electrochemical polishing
HRc	Hardness Rockwell C
ISO	International Organization for Standardization
LAM	Laser additive manufacturing
LENS	Laser engineered net shaping
LMD	Laser metal deposition

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The International Journal of Advanced Manufacturing Technology
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ORIGINAL ARTICLE

In-process chatter detection in micro-milling using acoustic emission via machine learning classifiers

Guilherme Serpa Sestito[1] · **Giuliana Sardi Venter**[2] · **Kandice Suane Barros Ribeiro**[1] · **Alessandro Roger Rodrigues**[1] · **Maíra Martins da Silva**[1]

Received: 19 January 2022 / Accepted: 8 April 2022

Abstract

Predicting chatter stability in a micro-milling operation is challenging since the experimental identification of the tool-tip dynamics is a complicated task. In micro-milling operations, in-process chatter monitoring strategies can use acoustic emission signals, which present an expressive rise during unstable cutting. Several authors propose different time and frequency domain metrics for chatter detection during micro-milling operations. Nevertheless, some of them cannot be exploited during cutting since they require long acquisition periods. This work proposes an in-process chatter detection method for micro-milling operation. A sliding window algorithm is responsible for extracting datasets from the acoustic emissions using optimal window and step packet sizes. Nine statistical-based features are derived from these datasets and used during training/testing phases of machine-learning classifiers. Once trained, machine learning classifiers can be used in-process chatter detection. The results assessed the trade-off between the number of features and the complexity of the classifier. On the one hand, a Perceptron-based classifier converged when trained and tested with the complete set of features. On the other hand, a support vector classifier achieved good accuracy values, false positive and negative rates, considering the two most relevant features. A classifier's output is derived at every step; therefore, both proposals are suitable for in-process chatter detection.

Keywords Micro-end milling · Machine Learning (ML) classifiers · Acoustic Emission (AE)

1 Introduction

Micro-milling manufacturing operations exploit reduced-sized end mills (tool) at high rotational speeds for producing complex-shaped components. Consequently, the dynamics and the cutting coefficients vary due to the elastoplastic behavior of the workpiece's material and the required high-speed values [1]. In addition, chip thickness variation can occur for a specific combination of process parameters due to the modulations left on the surface during the successive cuts (as illustrated in Fig 1). This complex interaction yields large forces and displacements that can promote chatter. This self-exciting vibration affects the surface finishing and reduces the tool life, affecting productivity.

Some authors have proposed modeling strategies aiming to monitor and predict this instability. For instance, Afazov et al. [2], and Jin and Altintas [3] proposed different chatter modeling approaches considering nonlinearities in the micro-milling cutting forces and damping process, respectively. Recently, Lu et al. [4] included the centrifugal forces and gyroscopic effects caused by the high-speed rotation of the micro-milling spindle in their modeling strategy, aiming for a more realistic representation of this phenomenon. Due to the variation of the dynamics, Graham et al. [5] presented two novel robust chatter stability models considering uncertain parameters. Recently, Mamedov [6] revised different modeling techniques related to the micro-milling process.

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CRITICAL REVIEW

Micro-machining of additively manufactured metals: a review

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Abstract

Metal additive manufacturing (MAM) has attracted significant interest in both academia and industry to produce near-net-shape engineering components. The inherent defects in MAM, however, require suitable subtractive techniques as post-processes to control dimensional and geometric tolerances as well as surface finish. The additively manufactured metals, with different microstructures than the wrought materials that produced by conventional routes, need different approaches and parameters when being machined. This review covers recent published literature on traditional micro-machining as a post-processing operation for MAM and recommends future directions. The text presents a brief review on the main AM processes followed by a comprehensive conventional micro-milling and microdrilling, as well as applications for micro-machining. Micro-tool assessment, built-up-edge prediction and prevention, and link of macro/micro-machining are areas for future research.

Keywords Metal additive manufacturing · Micro-machining · Tool assessment · Cutting fluid · Surface quality

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1059-9495/$19.00

Effect of Laser Polishing Post-Processing Technique on the Roughness and Wear Resistance of Inconel 625 Deposited by Laser Cladding on AISI 304L Stainless Steel

Fábio Edson Mariani, Kandice Suane Barros Ribeiro, Amadeu Neto Lombardi, Luiz Carlos Casteletti, and Reginaldo Teixeira Coelho

Submitted: 7 February 2021 / Revised: 1 May 2021 / Accepted: 15 May 2021

The use of laser cladding is a promising economic alternative for the production of coatings to with stand corrosion and wear, as well as for repairing aeronautical components after wearing out by using. Such technique allows the use of a wide variety of alloys for coating on flat and complex shapes, since it does not require strict controls compared to others powder-coating processes. The use of laser cladding is an ideal choice since it allows the deposition of superalloy on low-cost stainless steel substrate, for example. The resulting bimetalic material presents high performance at a much lower cost, hence making economically feasible a more intensive use of superalloys in many other circumstances. Inconel 625 alloy presents very high resistance to pitting in oxidizing chloride environments and good mechanical properties at elevated temperatures. Therefore, a hybrid metallic material made of AISI 304L stainless steel as substrate coated with Inconel 625 can be economically used in several situations with superior performance. However, surface finishing left by laser cladding is not always as smooth as required for most applications. In this work, coatings of Inconel 625 alloy were deposited by laser cladding on AISI 304L. The Inconel layer was post-processed by laser polishing (LP) for surface finishing improvements. The resulting coatings were evaluated for hardness, roughness and micro-abrasive wear tests. The LP post-processing significantly improved the roughness of Inconel 625 coating and did not significantly change its composition nor hardness. The coating layer also showed much better wear resistance, when compared to the AISI 304L substrate.

Keywords Inconel 625 coatings, laser cladding, post-processing, roughness, wear tests

1. Introduction

Many are the available machines for laser cladding (LC), including those used for additive manufacturing (AM) processes, such as Laser-Direct Energy Deposition (L-DED) (Ref 1-9). Such equipment allows building complex geometric shapes using one metal and coating it with a different one. Therefore, components can achieve better performance in service using, for example, the advantages of substrate mechanical properties and a surface resistance to wear and corrosion (Ref 9-11). Additionally, any laser post-processing can be performed inside the same machine with the same gripping position. Those resources together with CAD (Computer Aided Design) software and subjected to topological optimization result in reduced weight, lower material waste, shorter lead times, etc., (Ref 9, 10). When that equipment is integrated with the entire manufacturing environment, is therefore, part of the most advanced production system nowadays, called Industry 4.0 (Ref 1-9).

An AM machine equipped with a L-DED head can perform depositions and repairs on worn surfaces belonging to drive shafts, bearings, seals and couplers, which are normally considered non-repairable by conventional welding techniques (Ref 10). Thick or thin layers deposited by laser are metallurgically bonded to the substrate, resulting in adherent and continuous interfaces, unlike mechanically bonded ones, such as the thermal spray process (Ref 1-3). The laser beam concentrates a high energy density to completely melts a specified metal powder, forming a molten pool mixed with the substrate surface to produce a high-quality layer with fast solidification characteristics as expected (Ref 1-5). Compared with other surface enhancing techniques, LC has unique

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A novel melt pool mapping technique towards the online monitoring of Directed Energy Deposition operations

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Abstract

Although Directed Energy Deposition (DED) has more than a two and a half decade history, the difficulty of consistently controlling this process is still limiting its adoption. Achieving robust printing of arbitrary shapes with high-fidelity (macro-scale) geometry and uniform pre-determined microstructure throughout relies on careful coordination of many factors (some of which still rely on the knowledge of the system user). Key to this endeavor is controlling the activity of the melt pool and managing its influence on surrounding material (including due to reheating cycles). Even with emerging in-process melt pool control methods, translating ideal steady state melt pool models into practical use while creating arbitrary shapes on-the-fly can be difficult to visualize and validate. Despite recent advances in the field of melt pool control, intuitive visualization of melt pool signatures and confirmation of how they affect the quality of the deposition is yet to be found. A process control indicating possible flaws or defective regions in the material component, as well as certifying the uniformity of characteristics during deposition would be of great help to improve the process itself and further diffuse its application. This study presents the development of a novel and innovative method for acquiring, processing and visually showing DED process signatures to assess progress toward fully automated melt pool control. This methodology relies on incrementally building a map of actual process conditions by merging multiple data streams collected during the deposition process for each layer and then plotting the recorded signatures along the 2D toolpath position. This concept has been realized with a new software application called HeatMAP. This application uses data supplied by the AMBIT™ Melt Pool Measurement 'MPM' system wherein images from the melt pool are acquired by a CMOS camera and processed. A second data stream is simultaneously collected directly from the CNC including the actual feed speed and the nozzle positions by using the DTConnect software (an application developed in this study based on FANUC FOCAS library). A visualization of the merged data sets in the HeatMAP software then imparts to the user an intuitive way of assessing the process quality using visualization as an indicator of metallurgical quality. To demonstrate the utility of this approach, two sets of experiments were undertaken: one as a benchmark, where process signatures were captured by the MPM system in monitoring only mode and another with active closed-loop laser control. When the melt pool measurement system is used in closed loop mode, the laser power is varied in order to maintain a target melt pool area within a specific range. At present, image data was acquired and processed throughout two deposition strategies, which were used to prove the mapping concept, its capabilities and methodology. The methods behind HeatMAP and DTConnect presented in this study, demonstrate the potential for these applications to accelerate the development of more stable deposition parameters, and process planning and control in the future. Using the proposed control, improvements to material quality are expected in the DED process.

Keywords: Additive Manufacturing; Melt pool monitoring; Feedback control; Software development

1. Introduction

Directed Energy Deposition (DED) technology is a deposition technique where a feedstock material, typically in powder

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Evaluation of laser polishing as post-processing of Inconel 625 produced by Directed Energy Deposition

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Abstract

As one of the Additive Manufacturing (AM) technologies, Directed Energy Deposition (DED) inherited common concerns from the AM concept, such as the layer discretization process, which brings about the staircase effect, and the complex thermal reheating cycles that occur due to the scanning strategies. In this regard, diversification in slicing strategies and the application of post-processing techniques arises as a feasible way to reduce defects and the usual poor surface finishing of DED parts. This study combines the non-planar slicing strategy as toolpath for laser polishing (LP) in DED parts, evaluating the influence of such post-processing for surface finishing, geometry and hardness of the Inconel 625 truncated pyramid built by DED. This geometry was built by using planar slicing and zigzag scanning strategy in BeAM M250 DED equipment. The non-planar coordinates of the LP were applied at an offset in the external profile of the pyramid with support of an open-source software Slic3R. The workpieces were built with laser power of 500 W delivered at the 800 μm spot diameter with scanning rate at 2000 mm/min and powder flow of 7.5 g/min. Laser polishing was performed considering three levels of energy density (9.38, 11.25 and 14.06 J/mm^2) and the number of iterations (once, 3 and 5 times). Both, deposition and LP, were performed with local Argon gas shielding. Among the results, LP has shown to be a feasible post-processing technique to L-DED parts, which can improve surface finishing and shape, maintaining hardness. The energy spent LP causes the remelting of satellite particles and shown to be not enough to rearrange the microstructure. The non-planar slicing applied, as toolpath to the LP, comprises a new possibility allowing DED parts to have better results towards surface finishing with a clean and quick method of post-processing. This has shown to be beneficial to the efficiency of the post-processing stage by leading to a greater assertiveness of the process, less post-processing time and no waste of material.

Keywords: Additive manufacturing; non-planar slicing strategy; staircase effect; non-conventional post-processing; surface roughness

1. Introduction

Manufacturing Inconel 625 parts and features with complex shapes through conventional methods has been a challenge due to the material high hardness, low machinability and low thermal conductivity [1]. Thus, early in its development, Additive Manufacturing (AM) appear as an alternative process in that chain, overcoming some of those adversities, triggering a readily adoption to manufacture Inconel 625 components [2]. Several AM processes using laser, electron beam or plasma arc as an energy source for melting Inconel 625 powder and build parts have been developed [2]. The two categories of AM processes that has been reported to produce Inconel 625 are Powder Bed Fusion (PBF) and Directed Energy Deposition (DED) [3].

DED is an AM technology that adds material in a layer-by-layer motion, by the simultaneous deliver of material (powder or wire) to a melt pool generated by a focused energy source (laser, electron beam or plasma arc) [4]. This technology has been successfully introduced in industries by the appeal of a more economical alternative for refurbishing worn and damaged regions in mechanical components, molds and dies, etc. Also, DED has been used to build complex-shaped parts without the aid of support structures [5]. Although DED technology is just starting to be widely used and its sales are exponentially

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A Study of Different Deposition Strategies in Direct Energy Deposition (DED) Processes

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Abstract

The stepover of adjacent deposition lines (or beads), when stacking layers to build a 3D-solid shape, is found to be of great importance to minimize voidage and so, improving density of parts produced by the Directed Energy Deposition (DED) process. During such process, in which the stacking of layers occurs, the complex thermal activity of metal deposition affects the part geometry, microstructure, physical and mechanical properties. The correlation between deposition path, bead stepover, and the direct effect on the part density, microstructure and geometry distortions are yet to be found in the literature. Therefore, the aim of this study is to evaluate the effect of deposition paths and bead stepover on the final part geometry form, microhardness and density. In order to do so, four deposition paths (linear, zigzag, chessboard and contour) and beads stepover of 0.44 mm and 0.55 mm were performed on the production of Stainless Steel 316L cubes by a 5-axis laser based DED BeAM Machine Magic800 with laser spot size of 0.80 mm. The paths shown considerable influence on the variation of both final part geometry and density. Contour (spiral-like) was the path, which produced workpieces with finer form and finishing, with density and microhardness closer to the conventional AISI 316L material. The bead stepover was also found to influence the surface finishing, as larger critical valleys between adjacent beads were noticed when using the higher stepover value.

Keywords: Directed Energy Deposition; Toolpath strategies; Density analysis; Microstructure.

1. Introduction

Directed Energy Deposition (DED) process is an Additive Manufacturing (AM) process, in which a focused thermal energy source fuses material, in general metallic powder, or wire, by melting them during layer-by-layer deposition [1]. Such technology makes new metallic components, starting from a substrate, as well as, it repairs and rebuilds damaged and worn parts. This process is also well suited to make functionally graded material (FGM) used in several fields, such as, aerospace, military and medical. [2]. It can deposit many materials, including titanium-, nickel-, and iron-based, besides stainless steel with a relatively high deposition rate, compared to other AM processes. Moreover, it tends to produce a minor heat affected zone (HAZ), compared with welding repairing applications. [3]

The laser based DED is a result of several parameters interaction in a very complex phenomenon. Parameters involving the laser, the motion system and the material feeder are relatively stable in a commercial equipment. The manufacturer normally supplies those in a recipe, after extensive tests and improvements [4]. Other parameters related to the process, specifically the deposition pattern, are also important. Its selection is a key decision to obtain a good quality deposition.

The basis for deposition strategies (paths) follows CAM (Computer Aided Manufacturing) software recommendations, normally applied in milling operations. AM processes, such as DED, start with those paths, but new requirements arise when

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An Initial Investigation of Tungsten Inert Gas (TIG) Torch as Heat Source for Additive Manufacturing (AM) Process

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Abstract

Additive Manufacturing (AM) processes are gaining more steam in the last years, due to a series of advantages, such as capability of producing complex parts never possible before, low stock to be removed, complex parts in exotic materials, etc. However, energy efficiency, high costs and longer fabrication time, could be some of the drawbacks in the future. Welding processes can be used to produce pieces by AM techniques and their application has been intensified lately. Commonly, AM processes use MIG/MG and TIG and primarily with wire as stock material. Welding offers the advantage of producing large parts in lower time and material consistency is always good, since those processes have been greatly improved. In contrast, welding workpieces, generally, result with rough surfaces and poor geometric quality, which makes them not readily acceptable for most of the common machinery applications. The present work investigates the use TIG process with metal powder as stock material to produce workpieces, which are to be post processed by machining. The AM process is based on the Powder Bed Fusion (PBF) system. A simple one-axis moving system was produced to test the whole concept. Powder was preferred since it is readily available in variety of metallic alloys. Two powder grain sizes (***Gs***), three travel speed values (***f***) and three current levels (***C***) were tested producing weld beads of AISI H13 on a substrate of AISI 1020 plate. Beads were assessed by measuring external dimensions and looking at their microstructures. Additional tests were performed building straight wall stacking 10 layers with the best welding parameters found with the first trials. Results indicate that materials with good internal quality could be produced when making single beads and also building straight walls. These first trials show that the proposed process can be used as a promising hybrid process, using AM (PBF-TIG) and conventional machining at the same equipment. Future work will concentrate on adapting the welding and powder bed system in a machining center to further study the process.

Keywords: Additive Process, Hybrid process, Welding, Machining

1. Introduction

For the last years, Additive Manufacturing (AM) processes have been intensively adopted by the most different fields, such as, aeronautical, military, medical, etc. and producing some encouraging results to manufacture complex and high-value components. In general, 3D parts can be designed in Computer Aided Design (CAD) software, and then produced, without the need of conventional tooling. The use of high strength and reactive materials are one of the most attractive aspects of this new technology. According to ISO/ASTM2900-15 there are 7 categories of AM processes and two of them – Powder bed Fusion (PBF) and Direct Energy Deposition (DED) – use a beam (laser or electron) or an electric arc as primary energy source for melting the metal layer by layer through the deposition process.

The use of laser and electron beam is more advanced and specific machines for such applications are already available in

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ORIGINAL ARTICLE

Experimental correlation between acoustic emission and stability in micromilling of different grain-sized materials

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Abstract

Unstable cutting in micromilling could severely damage the tool and hinder the possibility to a usable machined part. This study proposes an experimental correlation between cutting stability, acoustic emission (AE) signal and roughness profile in micro-end milling operations. The monitoring of cutting stability occurred over the micromilling of two different grain-sized mid-carbon steel. The results have shown that the grain size influences the amplitude of AE signal. The root mean square of AE (AErms) has an expressive rise when performing unstable cutting in both workpiece materials, influencing the roughness surface levels. The index proposed to correlate the AErms data to the cutting stability is experimentally validated and a new threshold for chatter and chatter-free cut is proposed. Although AE in-process monitoring is feasible for recognizing chatter occurrence in micromilling operations and general profile patterns, an overall prediction of surface roughness depends on more than AE data.

Keywords Monitoring · Acoustic emission · Chatter · Micro-end milling · Workpiece grain size

1 Introduction

Micromilling operations involve a complex interaction that occurs between the tool-holder, the tool and the workpiece [1–3]. Due to the reduced dimensions of micromilling tools, they are inherently more susceptible to damage when undergoing severe vibration and chatter, a type of self-exciting vibration [4], which affects the workpiece finishing by increasing general roughness levels.

Chatter can arise due to such complex interaction and due to the chip formation process, leading to poor quality of machined parts, the necessity of rework, an increase in the tool wear and, therefore, a decrease in both the tool life and the overall productivity [5, 6]. Visually, chatter can be identified in micro-milled parts by the crossing on the feed rate lines in the machined surface [7]. Strategies to monitor [4, 8–10], predict [11–13], model [14–16] and control [17, 18] chatter are of paramount importance in the machining productivity research. In a well-monitored environment, a careful selection of cutting parameters can ensure a stable cut and minimize this issue [19].

In general, vibration and chatter monitoring on the machining process can be performed by acoustic emission [20–22], optical sensors [23–25], accelerometers or intelligent materials [26, 27]. Due to the precision required, there has been a predominance of monitoring systems through acoustic emission (AE), followed by accelerometers, laser interferometers and load cells [28]. Although accelerometers are the most widely used vibration transducers, which are extensively used to monitor chatter in cutting operations [29], monitoring the AE signals generated during cutting can detect not only the vibration but also the tool-workpiece contact, surface integrity and topography [28, 30–33]. In this respect, AE has also been applied to monitor surface roughness and finishing in some studies [34, 35], providing a multitude of information to be used in monitoring.

The monitoring techniques applied to AE signals have been largely studied in machining. Time frequency analysis, through short-time Fourier transformation (STFT), was used to transfer raw AE data into salient signal features in Griffin et. al. [36]. This information was used to correlate AE data to surface roughness in positions that were close to the AE

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EVALUATION OF THE RESTRICTED AIR ENTRY ON THE DISCHARGE RATE FROM SILOS

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Abstract. *Storage and distribution of solid materials, as well as control under powder discharge, has been fundamental to ore transportation and lately, Additive Manufacturing (AM). AM demands fine powders materials to be fed with high accuracy, by hoppers. It is not only the reliability of flow that becomes important but also to have a trace of repeatability of material discharges and flow characteristics. In this perspective, two types of hopper feeders have been utilized the most: screw feeder and scraper feeder. In the present work, the characteristics of a steady granular flow through an orifice in scraper feeders with a flat and conical bottom have been experimentally investigated under the influence of top ventilation. The discharge rate of granular particles of magnesium, alumina, glass beads and crushed glass have been studied as a function of the outlet diameter and the ventilation configuration. Tests were performed three times under the same configuration, which consisted for both apparatuses, a measurement of discharge time and the mass through outlet orifices of 15, 30 and 50 mm, with different vent area percentage. The results have shown that the discharge rate increases with the increasing outlet diameter and top ventilation in the majority of the materials studied. In both hopper geometries, a rise in mass flow rate was generally observed when ventilation was added to the system, even though the difference when doubled the vent area was not significant.*

Keywords: *Granular flow, Discharge rate, Bulk solids, Ventilation.*

1. INTRODUCTION

The impact of granular flow in daily lives is often understated, yet grains represent the second most common material displaced by humans (Kabla and Senden, 2009). In recent years, the area of bulk solids has been studied and a few centres have specialized in this field around the world (Ahn *et al.*, 2008). Storage and distribution of material, as well as control under powder for constant and precise discharge, is fundamental to food, ore, pharmaceutical industries, and any industrial application with solids handling (Suri and Horio, 2009). In this perspective, the advance of manufacturing processes that require powder feed lines such as in Additive Manufacturing (AM) of metals machinery, bulk solids handling becomes an interesting field of study for AM processes as Directed Energy Deposition (DED).

Some bulk and particle properties are fundamental for a better understanding of bulk solids challenges, and these properties include particle size and shape; size distribution; bulk densities; cohesive and friction properties; air permeability; flowability; explosibility; toxicity; and compressibility (Beverloo *et al.*, 1961). According to Ahn *et al.* (2008), particle size, shape and surface area together determine a very large extent in the degree of particles with the surrounding fluid. Materials within a particle size range in between 100-1000 μm are classified as a granular solid and are characteristic of easy flowing with cohesive effects at high percentages of fine particles (Schulze, 2008).

According to Bradley *et al.* (2001), a powder is compacted by its overburden, impact, and vibration of a storage structure. This compaction causes some powders to gain strength by cohesion and due to that, when the discharge gate is opened, some of the powder at the bottom of the hopper falls out. This procedure alters the powder distribution in the remaining material and this rearranging is the basic to explain the majority phenomena occurring during hopper discharge. In general, there is a small significant effect on the discharging mass flow rate decreasing as voidage in the material increases (Schulze, 2008).

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MONITORING MICRO-END MILLING STABILITY VIA ACOUSTIC EMISSION

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Abstract. *Regarding the reduced dimensions of micro-milling tools, a non-optimized selection of cutting parameters tends to increase tool wear and breakage throughout cutting operations. Even relatively small errors in placement or changes in the process damping could cause a previously stable cut to become unstable. As the cutting parameters in machining operations are most likely optimized and, therefore, on the threshold of instability, it is paramount to monitor the machining stability throughout cutting. The monitoring of machining processes provides informative outputs that can be used to control and better select the cutting parameters, improving productivity. This research provides a means to monitor micro-end milling stability using acoustic emission (AE) signals in machining of ultra fine-grained steel COSAR 60 (GUF). Cutting tests were performed by carbide micro-end mill tools with (Ti, Al, Cr) N coating, two flutes and 1 mm diameter in a CNC machining centre Romi D800 High Performance adapted with a high spindle speed head, in sloth cutting strategy with the cutting parameters at cutting speed $v_c = 125\ m/min$, feed rate $f_z = 3\ \mu m/edge$ and depth of cut $a_p = 100\ \mu m$. AE signals were acquired at the rate of 1.25 MHz in LabVIEW® and processed in MATLAB®. Images from the micro-channel surface obtained from a 3D laser microscopy were also analyzed. As a result, AE signals have shown an expressive rise in amplitude in specific frequencies when performing unstable cutting and it was possible to determine the chatter frequency. A dynamic analysis was carried out to evaluate the system's natural frequencies. The method of acoustic emission monitoring has been proved capable of recognizing cutting instability in micro-end milling operations.*

Keywords: *Micro-end milling, Cutting stability, Machining monitoring, Acoustic emission.*

1. INTRODUCTION

In the face of the technological advancement and its mechanical units, a search for machines that meet the requirements for manufacturing miniaturized and/or highly detailed parts has required great efforts in the area of precision machining. The miniaturization of components suggests an increase of value to the final product and thus it is believed that success in the supply chain is imperative when micro-milling operations has a successful optimized implementation (Tansel *et al.*, 1998).

As micro-milling tools have reduced dimensions, a non-optimized selection of cutting parameters tends to maximize tool wear and breakage in cutting operations. Moreover, the micro-milling tools are slender and tend to present low rigidity, contributing to elevated vibration (Cheng and Huo, 2013; Jin and Altintas, 2013) that pushes the cut to unstable regions, which is exacerbated by size effect and tool geometry (Griffin *et al.*, 2017). Even relatively small errors in placement or changes in the process damping could cause a previously stable cut to become unstable altintas,ventersilva2.

With regard to precision machining, there is a predominance of monitoring systems through acoustic emission (AE), followed by accelerometers, laser interferometers and load cells (Wang and Gao, 2005; Lu and Wang, 2013; Filippov *et al.*, 2018). This approach indicates that the surface integrity/topography, the process vibration and the anisotropy of the material are objects of study of AE systems in the great majority of precision machining.

AE is defined by the American Society for Testing and Materials (ASTM) as elastic transient waves generated by the