# A COLLABORATIVE STUDY ON THE CHARACTERIZATION OF ADDITIVE MANUFACTURING BUILD SURFACES AND SOLIDIFIED MELT POOL TOPOGRAPHY

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## INTRODUCTION

The combinations of additive manufacturing (AM) equipment, metrology systems, and experience in the research community is vast. Members of the research community have considerable knowledge and experience with their own equipment, but the wide range of process variables and variations in equipment across vendors makes conveying this experience challenging. Often this intangible experience is left out of technical articles due to space considerations and the extent to which research can be applied to the range of systems available is often unclear. However, when successful, collaborations among researchers can be a steppingstone to quickly broadening a research topic. For example, teams that have the ability leverage each other's research can use the collaboration to increase impact of future articles. This is achieved with the unbroken chain of research that leads back to the original work. That chain can provide tremendous detail that other groups can leverage to advance their, and our, understanding of the research.

To this end, a collaborative study began in mid-2023 and is currently underway with participants from the International Academy for Production Engineering (CIRP). The goal of the collaboration is to develop the framework that enables diverse groups of researchers to quickly leverage each other's work. The collaboration focuses on laser powder bed fusion (LPBF) AM, as this is the equipment the authors primarily use, but may be re-designed for other systems with similar thermal processes (e.g., directed energy deposition, electron beam powder bed fusion). An AM build geometry has been disseminated to participants, who will use the design to answer research questions relevant to their own equipment and materials.

In this poster, the geometry and measurands to characterize the surface topography in rapid turnaround regions (RTRs) are detailed. The build procedures and measurands are described such that they can be realized in a wide range of metrology equipment and will allow others to replicate the study or participate in the collaboration.

Finally, the framework for future collaborative cycles, which we will refer to moving forward as rapid knowledge transfer (RKT) cycles, is being developed through this work. If successful, further implementations of RKT cycles can bring diverse groups of researchers together in common goals, rapidly expand networks of researchers through the collaborative connections, and help share the vast amount of experience available through the CIRP members and greater research community.

## BACKGROUND

Conceptual models have been developed based on solidified melt pool structures observed in RTRs of parts [1–3]. While these models were developed from experiments using nickel superalloy 625, it is believed that they are extensible to additional materials and manufacturing equipment. These models are based on the concept that residual heat is creating regions where weld tracks are still molten or hot enough to be re-melted and merge with adjacent tracks. It is this to create an oversized melt pool.

## BUILD DESIGN & REQUIREMENTS

Each build consists of a variety of single layer samples built on top of a rectangular prism. The primary investigation will center on an octagonal "tile" geometry (see Fig. 1). The EOS system rotates the scan strategy by 67° each layer and (for a 40 µm layer thickness) the layer at 10.8 mm will have laser scanning directions perpendicular to the recoater motion and stepover direction parallel to the recoater motion. Thus, prisms here have a vertical dimension in the build direction of 10.76 mm but may need to be changed for other systems. A schematic of the prism is shown in Fig. 1, with included angles (α and β) from 5° to 45°. Pairings of α and β control the axial length of the sample. An example of the scan strategy of the tile is shown in Fig. 2.

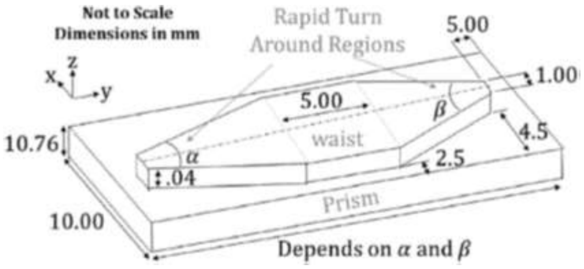

*Fig. 1. Schematic of the octagonal tile geometry atop a rectangular prism*

Each octagonal sample has a 5 mm square waist to restore nominal build characteristics between the two tapered areas of interest. The other single layer geometries include 10 mm long stripes at constant width (e.g., 1 mm and 2 mm), and a 10 mm "diamond square" (i.e., a 10 mm square, rotated such that the edges are 45° relative to the stepover direction). Beam-on-part single tracks are also included.

The build is designed to fit on an approximately 4-inch square and 0.5-inch thick subplate, which can be bolted to a larger build plate. This is to accommodate equipment that may have a smaller build area than the EOS M290 used in prior work. The subplate can be made from a different material than the feedstock (e.g., steel plates are commonly used regardless of feedstock material). A schematic of the build design shown in Fig. 3 (following page).

The build design is intended to represent the topography that is formed in the bulk regions of the build and not those at top surface of parts, where laser parameters are modified to improve final surface layer appearance. Therefore, the desired list of build requires requirements include:

1) Turn off "upskin" parameters
2) Turn off "contour" passes (if possible)
3) Turn off striping or maximize stripe width to prevent stripe boundaries from occurring within the part (if possible).
4) Report laser scan direction for top surface layers
5) Report step-over direction for top surface layers
6) The scan strategy should be configured such that the final layer of each part is manufactured sequentially, rather than having intermittent jumps between parts.

## MEASURANDS FOR CHARACTERIZING THE DISTORTED MELTPOOLS

The poster will provide several examples of measurands for the participants to reference. It is, however, difficult to anticipate every scenario that may cause inconsistencies or misinterpretations of the measurands for different topographical regions of interest. As such, the methods for the realization of the measurands of the distorted melt pools that form in the build samples are only examples. In many cases, multiple definitions of measurands can be determined (e.g., distorted melt pool length, height, width, etc.); however, determination of a definition that will best describe the behavior we wish to capture can be difficult. Additional measurands may be found during the collaboration as well.

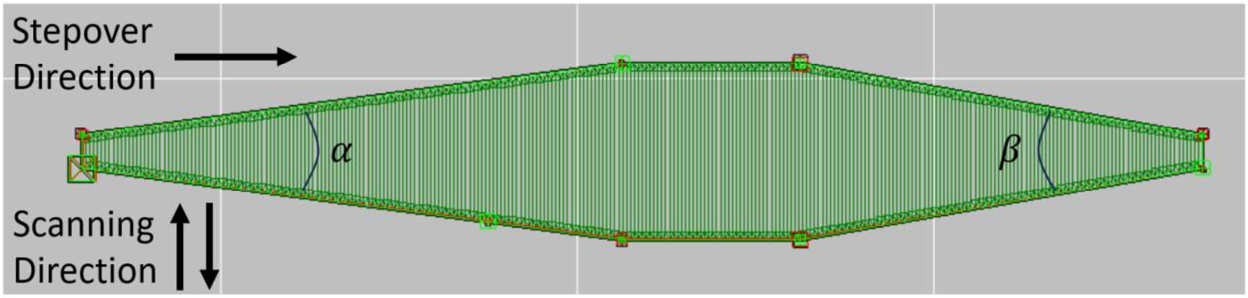

*Fig. 2.* Scan strategy for an octagonal tile geometry built at the 10.8 mm layer.

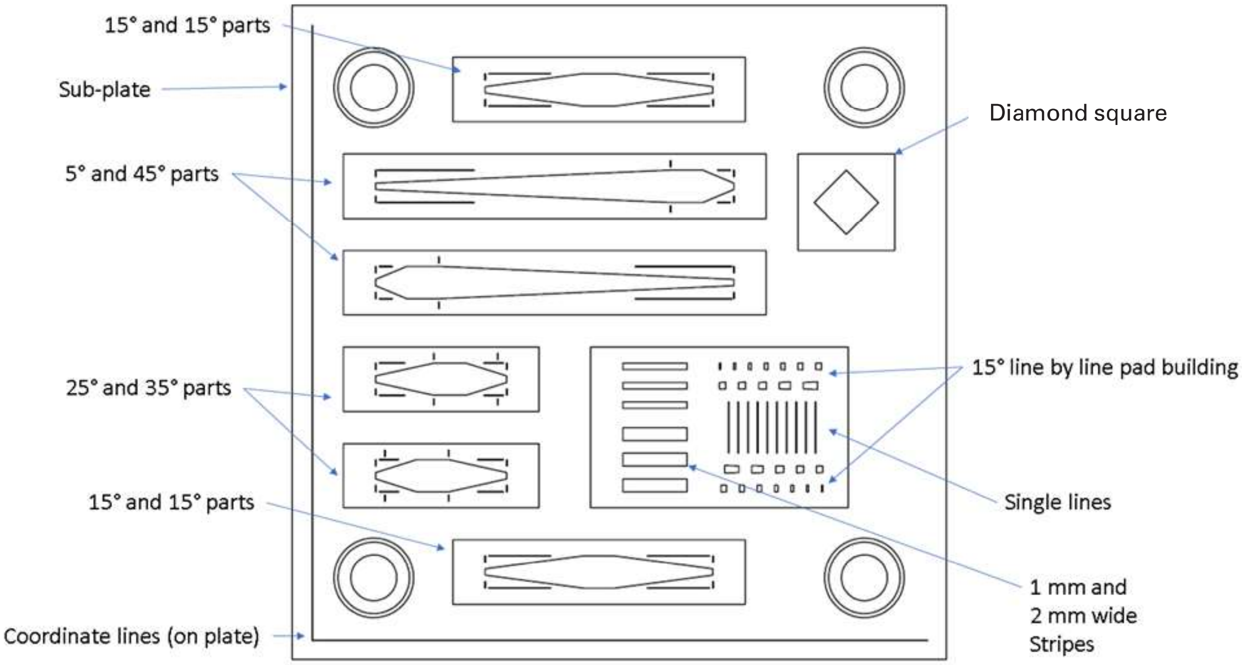

*Fig. 3. Example of the octagonal single layer samples and other standard parts to be built on one subplate as part of collaborative study.*

Measurands can range from distorted melt pool length, height, average curvature, volume, etc. Examples of developing measurands are provided in [4], which outlines a procedure for isolating the distorted melt pools and measuring the length. The region-based approach simplifies the realization of the other measurands: width, height, and volume. These measurands are also discussed in the current proceedings [5,6].

## CURRENT STATUS & NEXT STEPS

In the coming months participants are expected to complete the experimental builds. Measurements will then be performed by the participating organization and/or the authors. Through the collaboration, a wide range of equipment, alloys, machine types, measurement systems, etc. will be used. Considerations regarding uncertainty will also be addressed and stated along with measurement results. It is expected that these measurements can lead to a better meso and microscale understanding of the melt pool behavior and serve as a benchmark for validating heigh fidelity modeling. A final report of the results, lessons learned, etc. will be provided at the culmination of the collaboration, with any additional recommendations and plans for future work.

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