NSF HAMMER-ERC 2025 MakeOH/IO Challenge

Motivation

Metamorphic manufacturing (also called "robotic blacksmithing" or "CNC forging") is at the forefront of a new industrial revolution, transforming the metals manufacturing industry through an innovative approach to fabricating metal parts.

While previous automated metal fabrication methods (such as CNC machining and 3D metal additive manufacturing) have brought about the capability to rapidly create complicated metal parts, nothing beats the strength and toughness of forged metal components. Unfortunately, to create tooling for a hot forging press, a stamping press, a shape rolling line, or other capital-intensive hot forming processes is expensive and requires long lead times (not to mention an entire factory to house and support the equipment). This is neither agile nor cost effective if just a few parts are needed (which is the case for high value specialized components). It is important to develop a new technology to rapidly and cost effectively make low numbers of high value, forged-quality metal parts.

The NSF HAMMER Engineering Research Center (a decade-long initiative supported by the National Science Foundation) is fueling this metamorphic manufacturing revolution, by bringing CNC technology to metal forming. To foster innovation in this emerging field, we are introducing three challenges:

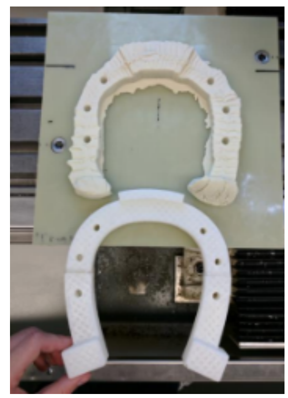
1. Form a part to a specific shape using plasticine, a modeling material that mimics the flow properties of hot metals at room temperature

2. Devise a machine vision system to analyze the geometry of the formed part to ensure it meets specifications

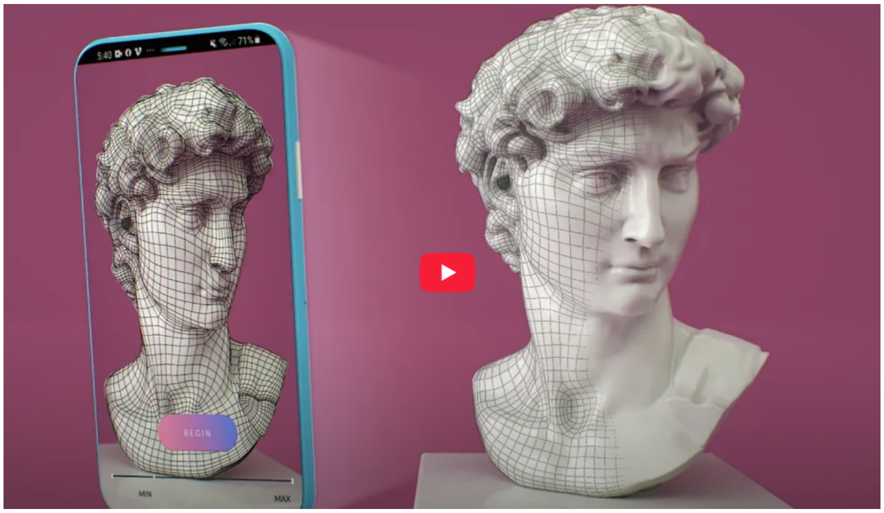
3. Develop a method to quantify the strain during or immediately after forming, enabling real-time comparison with predicted strain values.

Theory and Value

1. Plasticine has long been utilized as a "model material" for studying metal flow. Its flow behavior at room temperature closely resembles the way metals flow under hot forming conditions. As a result, "visioplasticity" studies visually examining the flow of plasticine during forming processes have offered significant insights into the flow behavior of metals during forming. By following the instructions in this challenge, you will develop an intuition for how metal flows during forming, and an appreciation for the type of tooling and steps necessary to create a forged metal part. Examples of formed plasticine parts are below *(Team Honey Badger, OSU Metamorphic Manufacturing Challenge 2017)*.

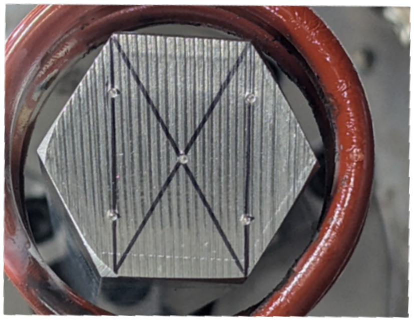


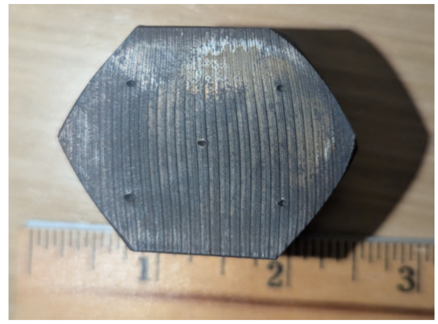
2. Ensuring that a formed component meets tolerance specifications is crucial for engineering quality. However, accurately measuring multiple features, particularly on contoured surfaces, can be challenging. A machine vision system that employs techniques such as photogrammetry, 2D laser line scanning, LIDAR, or similar methods is essential for capturing the full geometry of a part. While various affordable open-source systems are available, challenges remain in addressing issues like capturing crevices, hidden features, and managing variations in material color, lighting, and shadows. Exporting the geometry as an STL file or another 3D mesh format for comparison with an existing CAD model is a critical step for this challenge. *(@CGShortCuts YouTube image below).*



3. In addition to measuring a part's shape after forming, it is equally important to rapidly measure its geometry between forming steps to capture its evolution throughout the process. This serves two key purposes. First, it provides a mid-forming data point to compare the real-time shape with the predicted shape that guides the forming tool paths. If the comparison is favorable, the autonomous machine continues along the predefined tool path. If deviations are detected, the process can be corrected or halted. Second, it offers a means to approximate the "strain" induced in the part, representing the degree of plastic deformation. Strain is a critical factor in understanding the microstructure of a metal part, which in turn influences key properties like strength, toughness, fracture resistance, corrosion resistance, and creep resistance.

   The microstructure, composed of metal "grains," is characterized by their size, shape, and orientation, all of which are influenced by the degree of local deformation. Accurately tracking these deformations can be achieved through methods like studying a grid applied to the part, analyzing a known "speckle pattern," or employing advanced machine vision techniques to analyze edges and features. This challenge encourages teams to track strain at specific points, lines, surfaces, or features on the component. The measured strain will then be compared to predictions from Finite Element Modeling simulations of the same shape to validate and refine the process. *(NSF HAMMER-ERC hexagonal bar, before and after forging in the CNC Agility Forge, with 5-point fiducial marks on face deformed from original state to formed state).*





Challenge Details:

1. Use the plasticine and tools included in your kit to create a simulated metal formed component. Research online to find an industrial component that is best made by forging. Then create instructions regarding *how* you created your part as accurately as possible out of plasticine, and submit four photos (top, side, front, isometric). See Appendix A for example instructions. Winners will be the teams that provides photos that most closely approximate the original industrial part they were replicating.

2. a. Capture the shape above using 3D photogrammetry, 3D scanning, 2D laser line scanning, lidar, or any other technique that is *not* simply replicating the geometry manually via CAD.

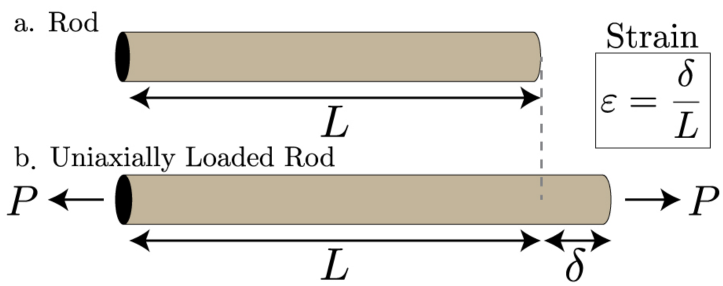
   b. Capture *any* shape with one of these techniques. Submit photos (top, side, front, isometric) of the object.

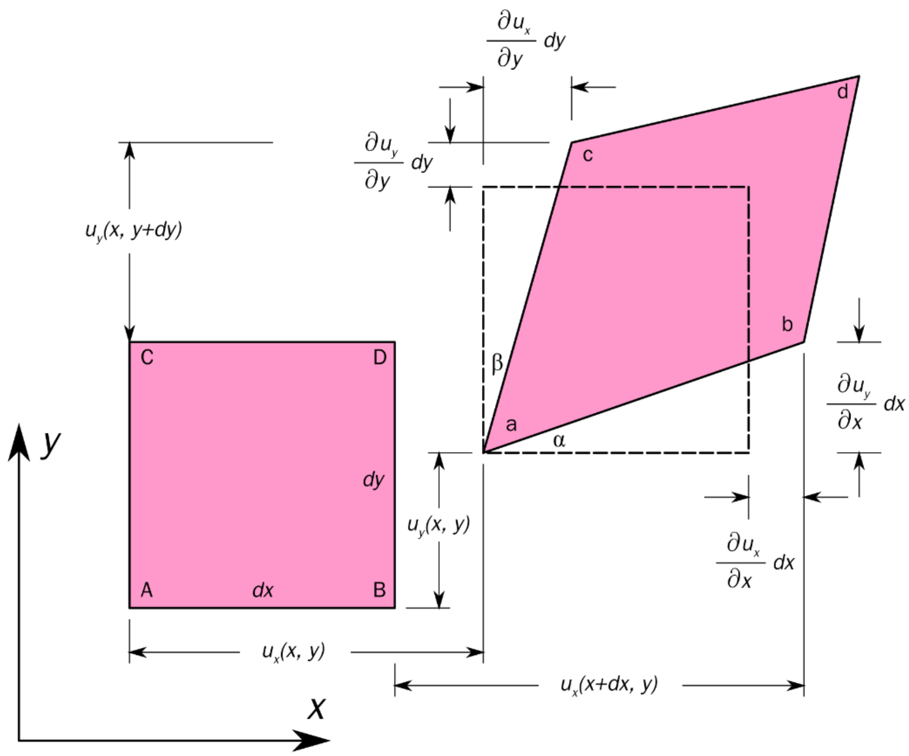
   Document your process in video and submit the video (both of the 3D data acquisition and the 3D conversion). (This is to identify the duration of your process).

   Winners will be the teams that provide the most accurate representation in the fastest time.

3. Capture the "strain" of the component as it is being formed.
   Tracking the change in position of a point on the formed part before and after forming, or the length of a feature, or a 2D pattern in a surface, will allow the

computation of “strain” accumulated during forming. *(One dimensional strain below, DroiteDesigns; two dimensional strain below that, Wikipedia).*





A simple example of strain might be to put dots on a face of a plasticine component, form it a little (documenting how you formed it), take pictures of how the dots evolved, form again, and repeat. Use the displacement of the fiducial dots to compute strain as a function of forming.

Appendix A

1. Start with 200 g of plasticine (provided in your kit)
2. Roll it into a sphere
3. Using a flat tool at least 6”x6”, press down ½"
4. The direction forward from you is X. The direction up is Z. The direction to your left is Y. The direction of your worpiece is x, y, z.
5. Rotate the object along x 90 degrees. Lay flat.
6. Apply ½" deformation in –Z.
7. Rotate 180 deg about x.
8. Apply ½" deformation in –Z.
9. Rotate 90 deg about y.
10. Apply ½" deformation in –Z.
11. Rotate 180 deg about y.
12. Apply ½" deformation in –Z.
13. Apply a mark at X = 0.5, Y = 0.5, ½" long, 45 degrees, with bottom left at X,Y.