

Metamorphic Manufacturing: The Third Wave in Digital Manufacturing

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Despite tremendous human limitations in sensing (eyesight), power (about one horsepower), computation (intuition) and reproducibility, the blacksmith can make an amazing array of components from many useful metals and often they are of very high quality. Further the smith often uses tricks to harden edges or provide anisotropic properties. Imagine what might be possible if a number of quickly advancing technologies were combined to make a machine that would essentially replicate a blacksmith. The technologies to be integrated may include:

- Dimensional sensors,
- Material State sensors that may measure temperature, strain, damage or other parameters,
- Closed-loop actuators (rollers, pinchers, etc.) and exchangeable tools producing large forces,
- Precise workpiece positioning via robotics,
- Precise local and temporal temperature control through induction heaters, lasers, infrared heaters, flames quench media and so on,
- Closed-loop control that may be enhanced with machine learning,
- Integrated Computational Materials Engineering (ICME) to predict local materials properties.

By combining these attributes, one could easily imagine the creation of the robotic analog of a blacksmith. This digitally controlled approach that uses closed loop control of deformation to create complex topologies and locally controlled microstructure, while maintaining a digital thread for quality assurance is presently defined as Metamorphic Manufacturing. With natural extensions, even local material chemistry could be controlled. Subtractive, additive and metamorphic manufacturing form the natural trinity of digital manufacturing approaches that are particularly adapted for metals. Each can provide great value when applied to appropriate manufacturing problems and there are obvious opportunities to join these basic approaches.

In one sense this area of metamorphic manufacturing is very similar to many well-developed areas such as open-die forging, cold forging and incremental bulk forming. Two things may be considered to be new with this approach. First is recognizing the synergistic value of integrating the rapidly maturing and disparate technologies listed above to produce a digital blacksmith. Second is identifying the need to rally the manufacturing community to develop practical, scalable integrated metamorphic manufacturing systems and the required training and supply chains. This will take many disparate skill sets. The Manufacturing USA Institutes are well suited to take on this kind of problem.