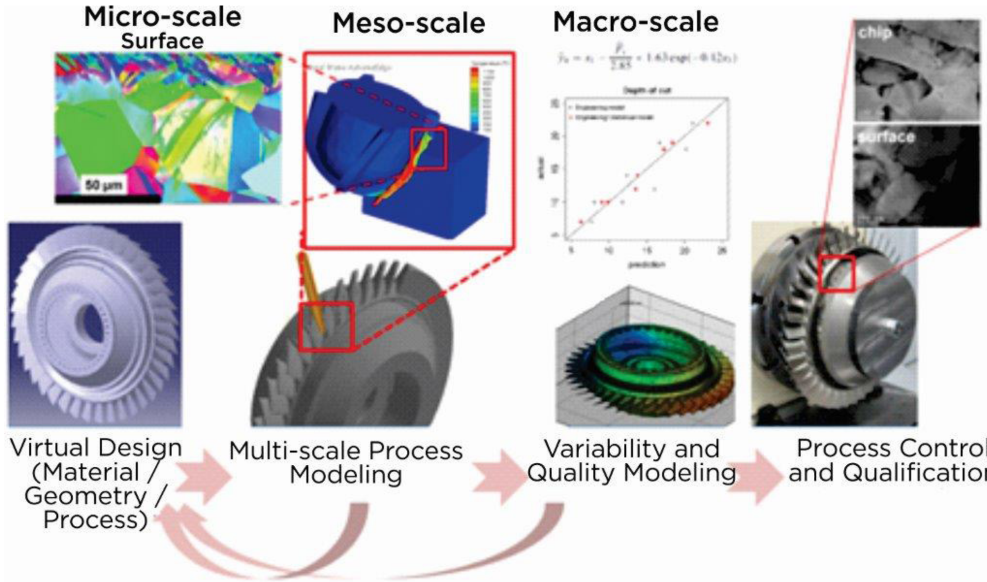
Sustainable Manufacturing via Multi-Scale, Physics-Based Process Modeling and Manufacturing-Informed Design

Improving Product and Manufacturing Process Design through a More Accurate and Widely Applicable Modeling Framework



Multi-scale modeling tools for enabling manufacturing-informed design. *Graphic credit Third Wave Systems.*

The goal of this project was to fill the knowledge gap between upstream design and downstream manufacturing processes by developing a manufacturing-informed design framework enabled by multi-scale, physics-based process models.

The developed framework enables product and process designers to:

- Evaluate the effects of design changes and material selection on component performance, cost, and quality.
- Anticipate manufacturing quality and cost issues ahead of shop floor implementation.
- Select and tailor manufacturing processes to achieve low-waste, low-cost processes without compromising quality.

During process or product design, U.S. manufacturers understand the characteristics and capabilities of manufacturing processes but do not account for the dynamic responses and variability of tooling, materials, and equipment. The design community lacks accurate, easy-to-use, detailed physics-based process modeling tools to inform and guide the design process through a better understanding of machining processes. Consequently, products and machining processes are often over- or under-designed, and design teams must perform many process trials that are based on conservative estimates coupled with slow cycle times, frequent tool replacements, and liberal use of cutting fluid. This inefficient trial-and-error process produces significant waste streams at the unit cell and plant level and incurs unnecessary financial and energy losses.

Available at every stage of a product's lifecycle, the computational tools developed through this effort help manufacturers accurately model machining processes, enabling improved productivity.

Benefits for Our Industry and Our Nation

The developed modeling advancements can provide a 50% improvement in machining process productivity. This productivity increase is achieved through the reduction of machining cycle times, waste streams, energy consumption, and carbon emissions while improving the energy efficiency of new product designs. Design engineers can use the modeling framework to develop lightweight, efficient products with optimal designs; and manufacturing engineers are able to design optimal manufacturing processes that require less energy and raw materials while assuring quality, performance, and costs. Ultimately, the computational framework and related tools promote sustainable manufacturing practices while preserving the economic and innovative edge of U.S. industry.

Applications in Our Nation's Industry

While the design framework initially focused on metal machining, its generic implementation is applicable to a broad range of manufacturing processes. The fundamental advances in material and manufacturing science present opportunities to improve casting, forging, stamping, extrusion, assembly, and additive manufacturing processes. The U.S. manufacturing supply base will benefit from improvements in productivity, quality, cost, and environmental impact – benefits most immediately realized by the aerospace, automotive, power generation, medical device, precision machining, and mining and heavy equipment manufacturing sectors.

Project Description

The project objective was to develop and demonstrate a new manufacturing-informed design framework that utilizes advanced multi-scale, physics-based process modeling to dramatically improve manufacturing productivity and quality while reducing the costs of machined components. A combination of advanced microstructural prediction models and physics-based modeling tools enable the framework to more accurately predict machined component quality and engineering performance.

Barriers

- Integration of multi-scale models.
- Computational modeling at the micro- and multi-scale level.
- Accuracy of the new physics-based process modeling components.

Pathways

The design framework was produced using an integrated approach that united relevant aspects of material science, manufacturing science, and statistical theory. Metal machining was used to demonstrate the framework and associated benefits. The four participating universities performed many of the needed analysis and modeling tasks.

Milestones

This project began in 2012 and was successfully completed in 2016.

- Demonstrate ability to predict trends in material characteristics in machined parts based on qualitative agreement of trends for extreme machining conditions.
- Establish capability to predict grain size and dislocation density based on first principles, as well as statistical models that incorporate variability into predictions of surface roughness and residual stresses.
- Demonstrate capability for advanced process optimization using algorithms that include control of workpiece surface characteristics.
- Demonstrate integrated framework for predicting and designing workpiece surface characteristics and component performance.

Accomplishments

The following design tools and capabilities were developed and enhanced:

- Advanced multi-scale microstructure prediction models
- Physics-based process modeling and optimization tools for rough and finish machining processes
- Advanced statistical models for capturing manufacturing variability

Commercialization

During the project, input from manufacturing stakeholders was incorporated to enhance commercialization. Third Wave Systems, Inc. will embed developed computational process modeling and optimization tools within its commercially available software to enable immediate adoption by U.S. manufacturers. Beta launch customers provided testing, technical guidance, and feedback during the entire project and will be closely involved in commercialization activities. The modeling architecture uses process modeling software, which enables rapid insertion into manufacturers' computer-aided design and production environments.

Project Partners

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