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Editorial: Advances of finite element methods in the precision manufacturing processes

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Editorial on the Research Topic
Advances of finite element methods in the precision manufacturing processes

Introduction

Manufacturing encompasses various physical phenomena, including processes for burr creation, plastic deformation, frictional contact, and thermo-mechanical coupling, among others. Undoubtedly, the most prevalent method for simulating manufacturing processes (Wifi and Orady, 1985) is the finite element method (FEM). The FEM, which has been continuously developing, can replicate experimental techniques to analyze manufacturing processes, especially when a vast array of intricate characteristics are involved, such as process parameters, non-linearity, complex work-piece materials and geometries, composite/multi-layered materials, shape memory alloys, and tool types. Therefore, "Advances of FEM in Precision Machining Processes" provides a concise analysis of the FEM's application to manufacturing processes (Fritz et al., 2002; Quiza, 2012). Current experimental data can be utilized to design and calibrate a finite element study. The difficulty in obtaining information near the cutting tool, which cannot be easily measured through experiments (many of which are laborious and expensive), such as strain, strain rate, the cutting force, and temperature, has driven researchers to gain a more profound understanding of the metal cutting mechanism via FEM.

Furthermore, the material constitutive law regarding flow stresses, the type of friction present at the tool-chip interface, and fracture control are all highly significant to the FEM analysis of machining issues (Quiza, 2012). The constitutive models applied in manufacturing processes and the following FE simulations to comprehend the characteristics (surface roughness, residual stresses, micro-hardness, plastic deformation, phase transitions, elastic recovery effect, ball indentation, and thermal behavior, etc.) are gaining increasing attention in both research and industry with the aim of enhancing the surface integrity of manufactured components.

Moreover, the advancement of manufacturing techniques for blazed grating structures (Ziqi et al., 2023) is essential for optical communication, structural coloration, precision measurement, and digital display. Therefore, the necessity for strong and reliable finite element (FE) techniques focused on different manufacturing processes such as 3D/additive manufacturing (AM), laser peening, ultrashort pulse laser ablation, machining, turning, and milling (Paweł et al., 2019), along with grating structure simulation, must be developed and subsequently integrated into artificial intelligence/machine learning (AI/ML) algorithms (Chengcheng et al., 2023) and digital production chains. Concerning laser processes, the intricacy and temporal sequence of the various phenomena that transpire when a laser beam interacts with matter render the finite element method (FEM) particularly intriguing and challenging. The speed of the processes and the parameters involved, their complex interactions, and the small regions affected render experimental measurements incredibly difficult. In these situations, FEM can significantly aid in comprehending the processes and enhancing the results.

This topic is captivating because it may enable new FEM applications in manufacturing. Ideal cutting parameters in machining, rolling (Gavalas and Papaefthymiou, 2020), turning, milling, and segments on high-speed machining (Satyanarayana et al., 2004), a vast array of laser applications in sheet metal forming, experimental and FEM analyses of tube end-forming processes, micro-manufacturing processes, and ball-burnishing processes through numerical and experimental simulations (Becerra-Becerra et al., 2023; Revankar et al., 2014), welding/EB welding, and the joining of various materials (high-strength steels, aluminum, titanium, and nickel-base steel) for aerospace applications, optimization of manufacturing processes utilizing AI and ML alongside FEM, additive manufacturing (AM), metallic powder bed AM processes, product development such as composite/multi-layered structures/products, and waveguides (Pany et al., 2001; Pany et al., 2002; Pany and Parthan, 2003a; Pany et al., 2003; Pany and Parthan, 2003b; Pany, 2022), acoustic metamaterials/phononic crystals aimed at vibration reduction (Pany and Li, 2023), spacecraft and antenna structures produced via 3D printing/AM, and the development of manufacturing methods for blazed grating structures, among other topics, are all examined through numerical and experimental approaches. This reflects the latest advancements in these sectors and the growing interest in both academic and practical investigations. Although these phenomena are widely recognized, most published works concerning manufacturing applied in engineering seek to establish theoretical and numerical methods to comprehend the mechanisms' behavior and its characteristics.

This Research Topic presents the recent novel trends in the Precision Manufacturing Processes using numerical techniques and the four research articles published were contributed by ten authors. The three original articles can be broadly attributed to three subtopic areas.

Influence of material orientation, loading angle, and single-shot repetition of laser shock peening on surface roughness properties. One article (Lebea et al.) explored the application of laser shock peening (LSP) as a method for surface modification to enhance the mechanical characteristics of implants. Titanium alloy Ti6Al4V is widely used in biomedical fields because of its remarkable biocompatibility, resistance to corrosion, and mechanical properties. The design of surface textures for dental implants has evolved over time to tackle challenges associated with oral rehabilitation in both healthy and compromised bones. The surface roughness of an implant considerably affects its durability. A numerical model has been created using the commercial finite element software ABAQUS/Explicit to replicate dynamic conditions. The objective of the study is to establish surface roughness parameters through computational techniques, as such investigations have not yet been considered.

Modeling the interaction between powder particles and laser heat sources. One article (Baloyi et al.) explored the spheroidization of titanium Ti-6Al-4V powder particles utilizing numerical models created in Abaqus and OpenFOAM. Spherical particles are essential in powder-based additive manufacturing because of their enhanced flowability, packing density, and mechanical properties, which improve printing accuracy and the quality of the final products. Although traditional methods like gas atomization and plasma spheroidization have been thoroughly examined, the possibilities of laser spheroidization remain inadequately investigated. To address this gap, comprehensive numerical analyses of laser spheroidization were performed, simulating heat transfer from the laser to powder particles using a transient uncoupled heat transfer approach that accounts for latent heat, while particle deformation was modeled with a phase-fraction-based interface-capturing technique combined with Navier-Stokes equations.

This research indicates that laser spheroidization of Ti-6Al-4V powder may enhance powder yield by 10%, providing greater power density and reduced melting durations compared to plasma spheroidization, thus offering a more effective option for producing spherical particles of specific dimensions.

Prediction of fatigue life of geometrically deviated steam turbine blades under thermo-mechanical conditions. In this subject, the Mashiachidi and Desai examined the complex elements impacting the fatigue lifespan of steam turbine blades, which include steam flow-induced bending, centrifugal forces, response to vibrations, structural mistuning, and influences that depend on temperature. By emphasizing the importance of mistuned steam turbine blades with varying blade shapes due to manufacturing tolerances, this study holds significant importance for the power generation sector. Utilizing finite element analysis (FEA) software, a basic, mistuned, scaled-down model of a steam turbine bladed disk was created, taking into account temperature-dependent material characteristics.

Finite element analysis and automation of a medium scale grinder applied to the manufacture of cassava starch. In this subject, the Gobi and Guo study focused on the modeling, internal structure examination, and automation of a cassava grinding machine. For the design, the single-cylinder grinder was selected because of its advantages, particularly simplicity and versatility. The automation of the grinder was implemented using a GRAFCET model and an advanced human-machine interface (HMI), adding an extra safety feature for the machine and enabling the operator to oversee the operation through an easy graphical interface. This automation facilitates continuous operation with minimal human involvement, thus enhancing the efficiency and safety of the cassava grinding process.

This Research Topic on Advances of Finite Element Methods in the Precision Manufacturing Processes marks the recent advances and insights in the field of structural mechanics and the growing interest in academic and applied research. We hope that the topic is interesting with the rapid development of manufacturing approaches, and methods, for new potential applications in the fields of additive manufacturing, metallic powder bed AM processes, optimization of manufacturing processes utilizing AI and ML, laser shock peening, composite/multi-layered structures, waveguides, metamaterials, PCs, vibration control, etc. The reported advances may help researchers study and better understand precision manufacturing processes applications.

Author contributions

CP: Writing – review and editing, Writing – original draft. DD: Writing – review and editing. WR: Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

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