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EDITORIAL

Revolution and challenges in machining processing aimed at carbon reduction

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The widespread use of cutting fluids during machining can effectively reduce machining temperatures, thereby solving the problem of part burns at the boundary of high thermal coupling. Cutting fluids have been extensively used in the manufacturing industry for hundreds of years; thus, the global annual consumption of cutting fluids exceeds 4 million tons. However, most of these cutting fluids are mineral oil-based emulsions, which are not environmentally friendly and renewable, which makes their use a huge challenge for sustainable manufacturing. At present, sustainable/green machining has become a hot topic in the manufacturing industry, especially due to the emergence of an international strategy called "peak carbon dioxide emissions." Emerging sustainable technologies (e.g., dry condition and minimum quantity lubrication) are increasingly being reported and preliminarily validated. However, certain limitations at various conditions (e.g., grinding, cutting, and milling) and application fields (e.g., aerospace field) have been found. Therefore, more attention should be focused on improving machining performance (e.g., energy reduction, improvement of efficient and quality, and suppression of machining defects) and understanding unknown mechanisms (e.g., atomization, infiltration, film-forming, and thermostability of biolubricant) by combining existing green and assistant technologies (e.g., low-temperature plasma and nano-enhanced biolubricants). Based on this information, the author's team planned the special issue entitled "Revolution and challenges in machining processing aimed at carbon reduction." This special issue aims to solve the problems regarding the unclear failure mechanisms of the nano-additive phase agglomeration of vegetable oil-based green lubricants; the lack of lubricant atomization, penetration, and film-forming and thermal destabilization mechanisms; and the bottleneck of insufficient sustainable manufacturing strategies.

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From the green lubricant preparation aspect, vegetable oil-based nano-lubricants have been proposed with higher heat transfer and tribological properties and were verified to reduce grinding force and temperature as well as improve the wear resistance in the grinding of aerospace alloy. Li's group [1] comprehensively reviewed the mechanisms and applications of vegetable oil-based nano-lubricants in machining. They performed a comparative assessment of grindability using titanium alloy, nickel-based alloy, and high-strength steel. They also considered the physicochemical properties as the main factors as well as analyzed the antifriction and heat dissipation behaviors of biolubricants in a high temperature and pressure interface. In addition, they conducted a comparative assessment of force, temperature, wheel wear, and workpiece surface for titanium alloy, nickel-based alloy, and high-strength steel. They found that high-viscosity biolubricants and nano-enhancers with high thermal conductivity are recommended for titanium alloy, thus solving the burn puzzle of the workpiece. A different option is available for high-strength steel grinding, which needs low-viscosity biolubricant to address the problems of debris breakage and wheel clogging. Furthermore, another study [2] deduced a milling force of the integral end milling cutter by force analysis of the milling cutter element and numerical simulation. The instantaneous milling force model of the integral end milling cutter was established under the condition of dry and nanofluid minimal quantity lubrication (NMQL) based on the dual mechanisms of the shear effect on the rake face of the milling cutter and the plow cutting effect on the flank surface. A single factor experiment was designed to introduce NMQL and the milling feed factor into the instantaneous milling force coefficient. The average absolute errors in the prediction of milling forces for the NMQL are 13.3%, 2.3%, and 7.6% in the *x*-, *y*-, and *z*-

direction, respectively. The results showed that compared with the milling forces obtained by dry milling, those by NMQL decreased by 21.4%, 17.7%, and 18.5% in the *x*-, *y*-, and *z*-direction, respectively.

From the action mechanism and processing properties of nanoparticle-enhanced coolants aspects, it has been verified to show improved performance and MQL than dry and traditional mineral oil-based cutting fluids. Li's group [3] also provided a comprehensive review of the mechanism of action and processing characteristics of nanoparticle-enhanced coolants. Their results showed the influence laws of nano-enhanced phases and base fluids on the processing performance, thus providing an explanation for the dispersion stabilization mechanism of nanoparticle-enhanced coolants in the preparation process. In addition, they combined the unique molecular structure and physical properties of the nanoparticle-enhanced coolant to elucidate its unique mechanisms of heat transfer, penetration, and antifriction effects. Furthermore, based on the excellent lubricating and cooling properties of the nanoparticle-enhanced coolants, one study investigated the effects of the nanoparticle-enhanced coolant by comprehensively and quantitatively evaluating the material removal characteristics during machining in turning, milling, and grinding applications. The study found that, compared with the conventional flood process, the turning of Ti–6Al–4V with multi-walled carbon nanotubes nanoparticle-enhanced coolant MQL with a volume fraction of 0.2% resulted in a 34% reduction in tool wear, an average decrease in cutting force of 28%, and a 7% decrease in surface roughness *Ra*. Based on the excellent performance of the nanoparticle-enhanced lubricant, they also performed experimental and simulation validation [4]. Molecular dynamic simulations were conducted for the abrasive grain/workpiece interface under NMQL, MQL, and dry grinding of Ni-based superalloy with three kinds of carbon group nanoparticles. The researchers utilized tangential grinding force and abrasive grain/workpiece contact states to evaluate the lubrication performance and to reveal the formation mechanism of the lubrication film. Their investigations showed the formation of a boundary lubrication film on the abrasive grain/workpiece interface under the MQL condition under the behaviors of rolling effect of nano-diamond, rolling and sliding effects of carbon nanotube (CNT), and the interlayer shear effect of graphene nanosheet. Moreover, under the NMQL condition, the carbon group nanoparticles further enhanced the tribological performance of the MQL technique that had benefited from their corresponding tribological behaviors on the abrasive grain/workpiece interface. Their results showed that compared with the findings under the MQL condition, the tangential grinding forces could be further reduced by 8.5%, 12.0%, and 14.1% under the diamond, CNT, and graphene NMQL conditions, respectively.

From the multienergy field assistance technologies aspect, it has been proven that high voltage electrostatic field and ultrasonic assistance can improve machining performance. In addition, it has been shown that a method called low-temperature plasma can effectively adjust material properties, including hardness, strength, ductility, and wettability, significantly improving material machinability. Liu's group [5] discussed the mechanisms and applications of low-temperature plasma-assisted machining as well as described the effects of the low-temperature plasma on different machining processes of various difficult-to-cut materials. They found that hot plasma improved material machinability via the thermal softening effect induced by the high temperature, whereas the main mechanisms of the cold plasma can be summarized as chemical reactions to reduce material hardness, the hydrophilization effect to improve surface wettability, and the Rehbinder effect to promote fracture. Furthermore, they analyzed hybrid machining methods that combined the merits of the low-temperature plasma and other energy fields, such as ultrasonic vibration, liquid nitrogen, and minimum quantity lubrication. Finally, they presented the promising development trends of low-temperature plasma-assisted machining, which include more precise control of the heat-affected zone in hot plasma-assisted machining, and cold plasma-assisted polishing of metal materials. They also further investigated the reaction mechanisms between the cold plasma and other materials.

From the machining sustainability aspect, sustainable production is based on the principles of high quality, high efficiency, energy savings, and emission reduction. Cai's group [6] conducted a study on the sustainability of machining from multiple dimensions. They explored the sustainability of machining from the aspects of equipment, process, and strategy and then analyzed sustainable machining-oriented machining equipment from the aspects of machine tools, cutting tools, and materials, such as cutting fluid. They also explored machining processes as important links of sustainable machining from the aspects of dry cutting, microlubrication, micro-cutting, low-temperature cutting, and multidirectional cutting. The strategies for sustainable machining were also analyzed from the aspects of energy-saving control, machining simulation, and process optimization of machine tools. Finally, they discussed various opportunities and challenges, including policies and regulations toward sustainable machining.

The papers published in this special issue revealed that milling forces of NMQL can be reduced by up to 21.4% compared with dry milling. The cutting force, tool wear, and surface roughness of NMQL can be reduced by up to 28%, 34%, and 7%, respectively, compared with conventional casting. Furthermore, the grinding force of CNT NMQL was reduced to 14.1% compared with MQL grinding, demonstrating a good example of the great potential of sustainable manufacturing in carbon reduction. We hope they could provide new ideas and methods for researchers regarding a new approach to machining processing based on emission and carbon reduction. We also hope they will promote the continuous research on machining processing theory, tools, lubricant, clean cutting equipment and key functional components, finally realizing the application and revolution of machining processing technologies in aerospace and other fields.

Special issue information

Achieving the global energy, sustainability, and decarbonization targets is highly reliant on new breakthroughs, ideas, and concepts. These significant achievements are cutting-edge “challenges” for researchers and engineers, and ***Frontiers of Mechanical Engineering*** contributes to the present discussion by proposing “the challenge-led special issue series.” Each special issue within this series aims to answer essential questions for the current state-of-the-art; thus, when looking at the papers published in the different special issues, researchers and engineers may find novel answers, suggestions, and ideas to achieve significant technical achievements.

The studies may include, but are not limited to the following topics:

- Nanofluid minimum quantity lubrication;
- Cryogenic minimum quantity lubrication;
- Electrostatic atomization-assisted minimum quantity lubrication;
- Material removal and damage mechanisms of composite materials machining with sustainable technology;
- Damage inhibition mechanisms of difficult-to-cut materials in green manufacturing;
- The advance application of sustainable manufacturing in the biomedical field;
- Machining performance of high/ultra-high-speed grinding with usage of minimum quantity lubrication;
- Infiltration mechanisms and properties of lubricants in complex grinding zones;
- Infiltration mechanisms and properties of lubricants at the microtextures of tool surfaces;
- Antifriction and antiwear behaviors of (nano-enhanced) biolubricants in cutting zones;
- Heat transfer mechanisms of (nano-enhanced) biolubricants in cutting zones;
- Atomization behaviors of lubricants with assistance from the field of electronics.

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Conflict of Interest The authors declare that they have no conflict of interest.

References

1. Cui X, Li C, Zhang Y, Ding W, An Q, Liu B, Li H N, Said Z, Sharma S, Li R, Debnath S. Comparative assessment of force, temperature, and wheel wear in sustainable grinding aerospace alloy using biolubricant. Frontiers of Mechanical Engineering, 2023, 18(1): 3
2. Duan Z, Li C, Zhang Y, Yang M, Gao T, Liu, X, Li R, Said Z, Debnath S, Sharma S. Mechanical behavior and semiempirical force model of aerospace aluminum alloy milling using nano biological lubricant. Frontiers of Mechanical Engineering, 2023, 18(1): 4
3. Hu S, Li C, Zhou Z, Liu B, Zhang Y, Yang M, Li B, Gao T, Liu M, Cui X, Wang X, Xu W, Dambatta Y S, Li R, Sharma S. Nanoparticle-enhanced coolants in machining: mechanism, application and prospects. Frontiers of Mechanical Engineering, 18(4): 53
4. Wang D, Zhang Y, Zhao Q, Jiang J, Liu G, Li C. Tribological mechanism of carbon group nanofluids on grinding interface under minimum quantity lubrication based on molecular dynamic simulation. Frontiers of Mechanical Engineering, 2023, 18(1): 17
5. Liu J, Li Y, Chen Y, Zhou Y, Wang S, Yuan Z, Jin Z, Liu X. A review of low-temperature plasma-assisted machining: from mechanism to application. Frontiers of Mechanical Engineering, 2023, 18(1): 18
6. Wang L, Cai W, He Y, Peng T, Xie J, Hu L, Li L. Equipment–process–strategy integration for sustainable machining: a review. Frontiers of Mechanical Engineering, 2023, 18(3): 36