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Construction of advanced machinery manufacturing technology case database based on China mechanical engineering technology development plan

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Abstract: The case database focuses on high-speed and ultra-high-speed cutting technology, additive manufacturing technology, composite processing technology, surface engineering technology, micro and nano manufacturing technology and other advanced manufacturing technologies, and collect academic frontiers in the field of machinery, engineering production practice and relevant scientific research achievements of project team members. After later construction and improvement, the case database can provide study and research reference for researchers and enterprise production personnel in the field of machinery and related professional fields. The construction of the case database also helps to promote school-enterprise cooperation, which is of great significance for further exploring the new mode of industry-university-research cooperation and promoting the training of application-oriented talents.

1. Introduction

There are still few teaching case studies on advanced mechanical engineering courses in mechanical engineering majors domestic and overseas, and the existing teaching case database construction is more concentrated in the undergraduate and junior college stages, while the research on teaching case database for professional degree postgraduates is very few. Although teachers have used some engineering examples in their previous teaching, however, these engineering examples have not met the requirements of a real teaching case. For example, the knowledge points contained are relatively simple, lack of comprehensiveness and systematism. Some teaching cases are based on theoretical knowledge and divorced from engineering practice. Many cases have been used for many years, and the application background involved is old, and cannot be well connected with the latest scientific and technological development frontier of the profession. Therefore, the good teaching effect of the case cannot be reflected, and it is difficult to achieve the training of graduate students' ability to analyse and solve problems, practical ability and innovative ability [1-2].

The implementation of systematic teaching cases for graduate students in mechanical engineering plays a crucial role in strengthening their mastery of theoretical knowledge, broadening their scientific research perspectives, and enhancing their innovation capabilities. This approach significantly improves graduate students' ability to analyze and solve practical problems while contributing to the construction and refinement of course systems.

2. Construction Scheme

According to the course connotation, teaching syllabus and teaching objectives of Advanced Mechanical Engineering for mechanical degree graduates, five technical topics are drawn up around the connotation and characteristics of advanced mechanical manufacturing technology, covering high-speed and ultra-high-speed cutting technology, additive manufacturing technology, composite processing technology, surface engineering technology, micro and nano manufacturing technology, etc. For each topic and key technology, five project cases were collected and organized [3-4].

2.1. Case 1: High speed and ultra-high speed hard turning process

High-speed and ultra-high-speed hard turning represent a significant application area of high-speed machining technology, enabling a new process that "replaces grinding with cutting." This process faces challenges such as high cutting forces and elevated cutting temperatures during operation, necessitating robust support from tools, machine tools, and fixtures. Firstly, the rigidity of the machine tool is a critical factor in ensuring the smooth progression of high-speed hard machining. Students should analyse whether the machine tool's rigidity is sufficient to handle the high loads associated with high-speed cutting. Secondly, the selection of tool materials and geometric structures is vital for machining effectiveness. Opting for tool materials with high wear resistance and thermal stability, combined with rational geometric design, can significantly enhance cutting efficiency and extend tool life. Additionally, by real-time monitoring of cutting forces, cutting temperatures, system vibrations, tool wear, and chips, an in-depth analysis of the mechanisms of high-speed and ultra-high-speed hard cutting can be conducted, thereby optimizing cutting process parameters. Ultimately, based on these analytical results, further refinement of the cutting process can be achieved to ensure the efficiency and stability of the machining process.

2.2. Case 2: Life prediction of composite coated carbide tool for high-speed cutting

The research investigates various life prediction methods for high-speed cutting composite coated carbide tools, with particular emphasis on establishing a comprehensive evaluation system for assessing the bonding performance at both the coating/coating and coating/substrate interfaces. Firstly, by analysing the influence mechanism of interface bonding performance on interface crack propagation, the relationship between interface bonding strength and crack propagation behaviour is revealed. Secondly, considering the microstructure and performance characteristics of the coatings, the effect of residual stress on interface crack propagation behaviour is studied to further refine the characterization system of interface bonding performance and establish the critical conditions for coating delamination. On this basis, numerical simulation research on the initiation and propagation behaviour of cracks at the coating/coating and coating/substrate interfaces is conducted, providing theoretical support for subsequent finite element simulation of wear in coated carbide tools. Simultaneously, students are guided to utilize the college's experimental equipment for tool life experiments, combining the evaluation results of the coating/substrate interface bonding performance to predict the tool's service life. Through a combination of experimental and simulation methods, a scientific tool life prediction model is established, offering theoretical basis and technical support for optimizing tool design and improving cutting efficiency.

2.3. Case 3: Laser surface polishing of additive manufacturing components

Laser additive manufacturing (LAM) technology has received considerable attention from academia and industry, and has been successfully applied in many engineering fields. However, due to the inherent "step effect", "balling effect", and "powder adhesion" interactions during the additive manufacturing forming process, the surface quality of the formed metal parts is poor, and cannot meet functional requirements such as assembly and friction. Therefore, this case proposes a laser polishing technology for additively manufactured components, guiding students to conduct research on the fundamental theory and performance technology of laser polishing for additive manufacturing surfaces, establishing a melting pool dynamics model to reveal the intrinsic action mechanism of thermal-stress coupling fields, and then conducting research on the surface morphology prediction and physical and mechanical properties of laser polishing, to provide theoretical support for the promotion and application of laser polishing technology in additive manufacturing surfaces and entire metal parts.

2.4. Case 4: Magnetic grinding and polishing of internal runner features for additive manufacturing

Metal additive manufacturing is an effective method for solving the complex internal flow channel component manufacturing problems in the aerospace and high-end equipment fields, but the surface quality of the formed parts is poor, and they cannot meet the high service requirements without post-processing. Polishing processing is a key link in the high-performance metal additive manufacturing technology chain. By letting students review the current polishing technologies for internal flow channel surface treatment, such as magnetic grinding, magnetic fluid processing, magnetorheological processing, magnetic field-assisted composite processing, magnetization tool processing, and magnetic jet processing, and comparing and analysing their advantages and disadvantages. Students are guided to understand the principle of magnetic grinding and its application for typical additive manufacturing bends, and analysing the key factors for achieving this polishing technology, students can establish a precise material removal model for the surface morphology characteristics of additive manufacturing based on finite element analysis. According to the principle of magnetic grinding polishing processing, as well as the type of work piece and processing position, the polishing device can ensure that the work piece is fixed and positioned reliably, the rotational speed of the magnetic poles can be adjusted, the gap in the processing area can be adjusted, the magnetic field strength in the processing area can be adjusted, and the processing area can be moved back and forth along the central axis of the test piece, and a patent for an invention can be written.

2.5. Case 5: Ultrasonic assisted progressive forming composite processing of aluminium alloy 5052 sheet

The digital incremental forming technology of plate materials has the characteristics of no need for special moulds, which can improve the forming limit of plate materials, be able to process plate parts with large deformation and complex shapes, and be easy to realize automation of plate forming. It is suitable for small-batch, multi-variety, and difficult-to-form sheet metal parts processing and new product development in the manufacturing industry, and has broad application prospects, which is a very promising advanced manufacturing technology. However, the insufficient geometric precision and surface quality of the forming process and the easy folding and rupture problems in the process of forming complex shapes with the existing incremental forming technology seriously restrict its widespread application. In view of this, this case proposes the key technology research of metal plate ultrasonic assisted digital incremental forming, can take aluminium alloy plate as the research object, by introducing ultrasonic vibration auxiliary energy to improve the plastic deformation behaviour of the plate material in the incremental forming process, to improve the material deformation limit, surface quality, precision and mechanical properties of the formed parts, and prolong the effective service life.

2.6. Case 6: Ultrasonic vibration-assisted micro-milling composite machining of Inconel 718

Ultrasonic vibration-assisted milling is an advanced machining technology that achieves vibrational cutting by applying ultrasonic vibrations to the tool or workpiece. Compared to traditional milling, this technology significantly reduces cutting forces and cutting temperatures while improving surface quality and enhancing the overall performance of the components. This case study focuses on the research of ultrasonic vibration-assisted micro-milling composite machining technology for Inconel 718 material, with an emphasis on exploring the effects of applying ultrasonic vibrations to the workpiece in different ways to achieve vibrational cutting. By appropriately selecting cutting parameters (such as cutting speed, feed rate, and depth of cut) and vibration parameters (such as vibration frequency and amplitude), the study investigates the optimization effects of ultrasonic vibration-assisted micro-milling on the machining process. Specifically, this technology effectively reduces the average cutting force and cutting temperature, minimizing thermal damage during machining. Additionally, ultrasonic vibrations introduce residual compressive stress on the component surface and refine the surface grain structure, significantly improving surface quality. These enhancements not only boost the fatigue resistance of the components but also improve their wear and corrosion resistance, extending their service life. This case study aims to guide students in deeply understanding the mechanisms of ultrasonic vibration-assisted micro-milling, mastering parameter optimization methods, and providing theoretical support and technical guidance for the manufacturing of high-performance components.

2.7. Case 7: Ultra-high strength steel Aer Met100 laser-assisted milling composite machining

Aer Met100 steel, as an ultra-high-strength steel, possesses excellent mechanical properties and is widely used in critical structural components such as carrier-based aircraft landing gears, jet engine shafts, and rocket casings. However, its difficult-to-machine characteristics lead to prominent issues such as short tool life and chip breaking difficulties. To address these challenges, this case proposes a laser heating-assisted cutting composite machining technology aimed at improving machining efficiency and quality. By comparing laser heating-assisted milling with conventional milling, the material removal mechanism is explored, and an analytical prediction model for the heat-affected zone in laser-assisted milling of Aer Met100 steel is established. Based on the moving continuous point heat source model and the superposition method of heat source temperature fields, precise prediction of the laser heating temperature field is achieved. Additionally, considering the material softening effect, a cutting force analytical prediction model is developed, and a method for solving the shear plane temperature and shear flow stress under the combined action of laser heating and plastic deformation is proposed. Furthermore, factors such as forces, heat, tool wear, and surface integrity (e.g., heat-affected zone and residual stress) in laser-assisted milling are analysed to provide theoretical support for optimizing the machining process. This research offers a new approach for the efficient machining of Aer Met100 steel and holds significant engineering application value.

3. Conclusions

With a focus on cultivating scientific research and innovation capabilities as the core objective, this study builds upon the construction of the aforementioned seven representative teaching cases. By integrating cutting-edge disciplinary developments, it guides graduate students to track the latest trends and explore hot research topics in the field of mechanical engineering. This approach effectively enhances graduate students' capabilities in mechanical innovation design and scientific research.

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