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Electric Discharge Machining of Insulating and Weakly Conductive Engineering Ceramics

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Foreword

China officially initiated 211 Project approved by the State Council in 1995. It was the biggest and most important project that was authorized by China in the higher education since the founding of New China. As a response to the domestic and international situation at the turn of the century, Chinese leaders made the important decision to develop the higher education 211 Project drives the overall development of participating universities through major innovations. It encompasses developing university subjects and teaching faculties, as well as other core elements aimed at improving university standards. The 211 project thereby explores successful ways to develop the high level universities.211 Project has been remarkably successful over the last 17 years. It has improved the overall educational quality of chinese higher level education, scientific research standards, and its institutional management and administration. The project has established the foundation for china to help top ranking universities operate at an advanced global level.

In 1997, the China University of Petroleum(UPC) was included in the 211 Project rankings, providing us with an opportunity to develop into a high level university. During the three phases (during the Ninth, Tenth and Eleventh Five-Year Plan periods) of 211 Project to date, the UPC has focused on improving the university's level; stated our mission to meet the needs of the petroleum and petrochemical industry; stated our goal to realize major innovative breakthroughs for national oil and gas; and aimed to improve of key discipline levels, create academic leaders, and cultivate international and innovative talents. We has adhered to the 211 Project development guidelines, and has used our advantages to drive overall improvements and developments. Our competitiveness has been significantly strengthened, and the university's administration and overall strength have noticeably improved, establishing a solid foundation for a world-class petroleum research university.

Participation in 211 Project has strengthened the university's petroleum characteristics and has highlighted our academic advantages. Moreover, we are smoothly implementing our specialty innovation platform. Five of the UPC's national key disciplines and two of our state key (cultivation) disciplines are at leading domestic/international advanced levels.

The UPC's engineering and the chemistry departments entered the Essential Science Indicators' world rankings for the first time in March 2012, indicating that the strength and the level of the two main subjects (the petroleum and petrochemical disciplines) have significantly increased. Our high-level teaching staff structure has substantially progressed. Our staff includes members of the Chinese Academy of Science and Engineering, distinguished Changjiang Scholar professors, national science fund for distinguished young scholars winners, and national 'Thousand Person Plan'and 'Millions of Talents' project candidates among other high-level talents. This provides an intellectual guarantee for the university's future. Innovation ability has substantially improved, and high-level programs and achievements are constantly emerging. Our annual scientific research funds are over 400 million RMB. The UPC has preliminarily established a science and technology innovation system with distinctive petroleum features, and has become an important element of the national science and technology innovation system. Our ability to cultivate innovative talents is improving. The UPC has undertaken a plan to educate and train outstanding engineers, and established a special zone for outstanding innovative talents. We are actively exploring ways to cultivate international talents, and have reformed our postgraduate education mechanism, preliminarily formed an innovative talents cultivation method and a postgraduate education mechanism corresponding to innovative talent cultivation.

We are perfecting our public service support system, We has developed an efficient and fast public service system, significantly upgraded our software and hardware.This provides a strong support basis to develop teaching, scientific research and management levels.

The experiences gained in the 17 years that UPC has been involved in 211 Project are invaluable.First, we must adhere to our guidelines and pioneer discipline innovations by strengthening our characteristics and stressing our advantages. We can thereby realize the goal of building a world-class petroleum department. Second, we must keep abreast of ongoing developments and overall improvements to further widen our advantages. We must coordinate our development and constantly improve our overall competitiveness by promoting the whole through the key parts.Third, we must adhere to the goal of improving our educational mechanisms and establishing our research platform. We must strengthen the overall university structure, collect resources, integrate our talent teams, and optimize all of the management sessions and working systems. We will achieve this by perfecting our educational mechanisms: focusing on elements such as integration, openness, common sharing, competitiveness, information flow, and our project administration mechanisms to ensure that all project work is conducted efficiently and effectively. Fourth, we must focus on staff recruitment and development, and cultivate a talented and united workforce. We must attract outstanding talents to form a team with dedicated and innovative members to promote 211 Project development, which support all of the university's undertakings. Internal schools, disciplines and relevant departments should coordinate and cooperate with one another to form a strong joint effort and guarantee that all of the development goals are smoothly implemented.

We gained invaluable experience since the implementation of 211 Project. It is necessary to carry these experiences forward to further develop the university into an outstanding research institute. To summarize the university's 211 Project experience and its successful outcomes, the UPC initiated a special fund in 2008 to finance the publication of a series of academic monographs relating to the project. These publications relate to both the implementation of 211 Project in the UPC and the scientific research achievements of talented UPC scholars. These monographs introduce and demonstrate the subject construction, scientific innovation and talent cultivation in different categories.

I believe that this series of monographs will disseminate our advanced scientific research results and our academic thoughts from different perspectives and multiple dimensions, and demonstrate the remarkable achievements made and development route taken during our implementation of 211 Project to date. They will support our social influence, improve our academic reputation and make an important and unique contribution to our ongoing 211 Project development plans.

Finally, I am grateful to all of our scholars for their hard work and considerable efforts for 211 Project. I commend the monograph authors in the dedication of collecting and summarizing all our research results. They will leave innovative results and academic spirits, and make invaluable contributions to our university, our faculities, the staffs and the students.

President of China University of Petroleum (East China)

September 2012

Preface

Engineering ceramics have the advantages of good mechanical properties, chemical and thermal stabilities at elevated temperature and excellent electrical performance. Hence, they have been widely used recent years in the machinery, electronics, metallurgy, chemical, geology, aerospace, and nuclear industries. The requirement on the precision, efficiency, and surface integrity of the component is higher and higher. However, it shows low efficiency, high cost, and poor surface integrity when machining them with the present machining methods. Electric discharge machining (EDM) is a non-traditional machining process removing material by a succession of repeated electrical discharges between an electrode and a workpiece. Since the electrode does not contact with the workpiece during machining, EDM is an effective and economical technique for machining conducting ceramics with any rigidity. However, the usually engineering ceramics are insulating or weakly conductive, and EDM cannot be directly used to machine these materials. The development of the process for electric discharge machining of insulating and weakly conductive engineering ceramics is an important research topic in the field of non-traditional machining. The authors have been engaged in the theoretical analysis and experimental investigation on this topic for more than twenty years, and obtained some achievements.

Therefore, we write the book, focusing on the various new machining methods and the machining mechanism for electric discharge machining of insulating and weakly conductive engineering ceramics. More people can understand the progress about the topic by this book, by which to promote the application of the insulating and weakly conductive engineering ceramics, enlarge the application field of electrical discharge machining technology, and enrich the theory of non-traditional machining.

The book is structured as follows:

Chapter 1 presents a new process of machining insulating engineering ceramics using electrical discharge (ED) milling, which is able to effectively machine a large surface area on insulating ceramics, and effectively machine other advanced insulating materials such as cubic boron nitride (CBN), polycrystalline diamond (PCD). The machining principle and characteristics of the technique are introduced. The effects of various machining parameters on the process performance have been investigated.

Moreover, the mathematical models of thermal eroding insulating ceramics with a single pulse discharge are established.

Chapter 2 presents a new method which employs a high energy capacitor for electric discharge machining of insulating ceramics efficiently. The process uses the high voltage, large capacitor and high discharge energy, it is able to effectively machine insulating ceramics, and the single discharge crater volume of insulating ceramics can reach 17.63mm^3. The effects of polarity, peak voltage, capacitance, current-limiting resistance, tool electrode feed, tool electrode section area and assisting electrode thickness on the process performance such as the single discharge crater volume, the tool wear ratio and the assisting electrode wear ratio have been investigated.

Chapter 3 focuses on electrical discharge and grinding with synchronous servo double electrodes (EDGSSDE) for insulating engineering ceramics which integrates electrical discharge and mechanical grinding with a metal bonded diamond conductive wheel. The effects of electrical parameters on material removal rate and surface roughness of the insulating ceramics are discussed. Moreover, a finite element-based analysis of residual stresses in insulating ceramics with this method is presented.

Chapter 4 investigates the effects of the electrical resistivity and the EDM parameters on the EDM performance of engineering ceramics in terms of the machining efficiency and the quality. Moreover, this chapter employs a steel toothed wheel as the tool electrode to machine SiC ceramics with specific resistivity of 500Ω·cm using electrical discharge milling, which is able to effectively machine a large surface area on SiC ceramics with electrical resistivity of 500Ω·cm, and effectively machine other advanced materials with high electrical resistivity such as polycrystalline diamond, and cubic boron nitride.

Chapter 5 presents a new process of machining weakly conductive engineering ceramics using end electrical discharge milling, which employs a turntable with several small cylindrical rods as the tool electrode, and uses a water-based emulsion as the machining fluid. The machining principle and characteristics of the technique are introduced. The effects of machining parameters on the process performance have been investigated with Taguchi experimental design method. Analysis of variance (ANOVA) and *F*-test are used to indicate the significant machining parameters affecting the machining characteristics. Furthermore, mathematical models relating to the machining characteristics are established with the stepwise regression method.

Chapter 6 proposes a new technology of machining SiC ceramics with electrical discharge milling and mechanical grinding compound method. The effects of pulse duration, pulse interval, peak voltage, peak current and feed rate of the workpiece on the process performance such as material removal rate, relative electrode wear ratio and surface roughness have been investigated. A L_{25} orthogonal array based on Taguchi method is adopted, and the experimental data are statistically evaluated by analysis of variance and stepwise regression. In addition, the surface microstructures machined by the new process have been observed by a scanning electron microscope (SEM), an X-ray diffraction (XRD) and an energy dispersive spectrometer (EDS).

Chapter 7 presents a compound process that integrates end electrical discharge milling and mechanical grinding to machine weakly conductive SiC ceramics. The process employs a turntable with several uniformly-distributed cylindrical copper electrodes and abrasive sticks as the tool, and uses a water-based emulsion as the machining fluid. End electrical discharge milling and mechanical grinding happen alternately, and are mutually beneficial, so the process is able to effectively machine a large surface area on SiC ceramic with a good surface quality. The machining principle and characteristics of the technique are introduced. Moreover, Taguchi experimental design, analysis of variance and stepwise regression are used to investigate the effects of machining parameters on performance parameters and surface integrity.

Chapter 8 fouses on the machining fluid for electrical discharge machining of engineering ceramics. Three kinds of emulsion are developed as the dielectric during electrical discharge machining of engineering ceramics, and the effects of dielectric and machining parameters on the process performance have been investigated.

In writing this book, we have benefited a great deal from a large number of individuals who have contributed immensely to this work through either valuable discussions, comments on earlier drafts, or strongly believing in this project and how it was conducted. In this regard, we are indebted to Jianhua Zhang, Yanting Zhang, Guoming Chen, Wensheng Xiao, Qingyun Li, Xiaopeng Li, Lili Yu, Fei Wang, Zengkai Liu, Ruiqiang Diao, Chenchen Xu, and Guangxu Wang. We would also like to thank China University of Petroleum for their support for publishing this book.

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Qingdao, China
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