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学位の種類	博士（工学）
学位記番号	博理工 678 号
学位授与年月日	令和３年３月２３日
学位授与の要件	学位規則第５条第１項該当
学位論文題目	ELID 研削とファインバブルクーラントを組み合わせた新たな加工システムの提案
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論文内容の要旨

In recent years, in the manufacturing industry, factors such as quick delivery and increased price competitiveness have become critical owing to high-mix low-volume production. Therefore, attempts to improve machining efficiency for cost reduction are being prioritized.

Electrolytic in-process dressing (ELID) grinding is a highly efficient machining method. In ELID grinding, dressing is performed automatically by setting the ELID grinding wheel as the positive electrode, maintaining the negative electrode in the vicinity, and supplying voltage between the grinding wheel and negative electrode to selectively remove only the metal bonds of the grinding wheel in use. In this process, as grinding can be performed stably without clogging, this method is applied widely to various grinding processes, ranging from high-performance roughing to mirror surface finishing. Therefore, as electrolytic dressing of the grinding wheel is performed via the grinding fluid, we have focused herein on the grinding fluid and studied the processing technology using fine bubbles (FBs) for high-performance grinding.

An FB is an air bubble with a diameter of less than 100 μm. It has been demonstrated that, for FBs, a decrease in the rising speed in the fluid follows a decrease in the air bubble diameter, and an increase in the pressure inside the air bubble occurs with decreasing air bubble diameter. These effects enable easier dissolving of the air inside the bubble. Therefore, the fluid characteristics can be controlled by using various gases and by changing the grinding atmosphere. In addition, an FB has a negative zeta potential; thus, it is attracted to the grinding wheel, which is the positive electrode, during ELID grinding. Furthermore, the zeta potential of an FB is influenced by the pH value; thus, the higher is the pH value, the higher is the zeta potential. Consequently, in a grinding fluid with low alkalinity used for ELID grinding, the zeta potential is expected to have a large negative value. The use of grinding fluid containing FBs for ELID grinding is believed to result in concentration of gases on the grinding wheel surface, thereby providing functionality to the grinding wheel surface and enabling high-performance grinding.

Based on this background, the objectives of this study are to: (1) investigate the effect of grinding fluid containing FBs (FB coolant) on the grinding process; (2) clarify the effect of applying FB coolant to ELID grinding; and (3) propose a novel processing method combining a conductive rubber-bonded grinding wheel and ELID grinding using FB coolant for the finishing process from an engineering perspective.

This thesis is organized as follows:

Chapter 1 presents an introduction including the background and objectives of this study.

Chapter 2 describes the basic properties of the FB during the grinding process. The FB condition, which contributes to the suppression of clogging, was clarified through grinding tests using FB coolant with an adjusted air intake volume. In addition, it was clarified that the use of FBs during grinding is expected to reduce the wear and clogging of the grinding wheel surface owing to the reduction in grinding force. Furthermore, it was possible to adjust the grinding fluid characteristics by using the FBs of various gases, and the wear of the grinding wheel was reduced using AirFB, CO_2FB, and N_2FB relative to normal grinding.

Chapter 3 describes FB-ELID grinding, which is a technique involving combination of FB coolant and ELID grinding. The behavior of FB during ELID grinding was examined, and the attraction of FB to the anode during ELID was verified. In addition, through grinding tests involving FB coolant and ELID grinding, it was clarified that FB-ELID

grinding can suppress the clogging of the grinding wheel surface. Moreover, as a way to improve the function of FB-ELID grinding, CO_2FB-ELID processing, which combines CO_2FB coolant and ELID grinding, was proposed. The results of the friction test demonstrate that the friction coefficient can be reduced through the effect of FBs, and the ability to remove the workpiece can be improved by the effect of CO_2FB. Furthermore, through the grinding experiment, it was clarified that stable machining can be performed, and that a significant amount of the workpiece can be removed by suppressing the wear of the grinding wheel.

Chapter 4 describes the finishing technology combined with a conductive rubber-bonded grinding wheel and FB-ELID grinding. A novel grinding system using O_2FB coolant was proposed to realize high-performance ELID grinding using a conductive rubber-bonded grinding wheel. It was found that the O_2FB coolant increased the amount of dissolved oxygen in the grinding fluid significantly. In addition, the O_2FB in the fluid was drawn to the conductive rubber-bonded grinding wheel, which is the positive pole, during the ELID. These effects are considered to enhance the dressing performance of conductive rubber-bonded grinding wheels. In the grinding of pure titanium using the proposed grinding system, mirror surface finishing was achieved while increasing the amount of workpiece removed, as compared to the cases when ELID was not employed and when ELID grinding was performed using a normal coolant. The effects of ELID grinding on surface modification were also observed, leading to confirmation that the proposed grinding system involves formation of a thick oxidized film on pure titanium. Moreover, the mechanism of the singular phenomenon in CO_2FB-ELID grinding using a conductive rubber-bonded grinding wheel with lubricity was investigated. Through the grinding tests employing a grinding wheel with different rubber materials and adjusted acrylonitrile (AN) content, the amount of removed workpiece was increased in the case of a butyl rubber-bonded grinding wheel under ELID grinding. In contrast, when a nitrile butadiene rubber (NBR) grinding wheel with adjusted AN content was used, a large amount of AN resulted in a larger amount of workpiece removed under ELID grinding. Consequently, it was clarified that the expression of functionality in ELID grinding using a conductive rubber-bonded grinding wheel with lubricity results from gas permeability.

Finally, Chapter 5 presents the conclusions and summarizes the results obtained in this study.

論文審査の結果の要旨

昨今の製造業においては，多品種少量化に伴う短納期化及び価格競争力強化のための低コスト化に対する要求が非常に大きくなっている．このような背景から加工能率向上への取り組みが非常に重要となっている．この課題の解決を目指して，ファインバブル（FB）を援用したELID研削加工技術について（1）FBを含む研削液（FBクーラント）が研削加工への影響（2）ELID研削にFBクーラントを適用した際の効果　（3）チタン合金の最終仕上げ加工特性の観点から検討している．

本論文では，FBを用いた研削実験系を構築しFBが研削時の研削特性におよぼす影響を調査した．実験の結果，FBを用いた研削で通常研削に比べ除去量の増加および砥石摩耗量の低減効果があることを示した．さらにFBクーラントとELID研削を組み合わせた加工法の提案し，ELID研削時にはFBが砥石に引き寄せられる効果を確認し，加工においてはFBにより目づまりの低減に寄与することを示した．これより，研削実験を通じて安定した加工を行うことができ，かつ砥石の摩耗を抑えて多くの被削材を除去できることが明らかとした．また，構築したシステムと導電性ラバーボンド砥石を用いた仕上げ加工技術についても検討し，工業的な利用法も提案している．

以上の結果は，研削加工の高効率化・高度化および製品の高付加価値化に資する技術であると考える．

以下に，「茨城大学大学院理工学研究科における博士学位論文の評価基準」に照らして評価結果を述べる．

（1）本論文では，第1章において，研究の目的および当該研究分野の位置づけを明確に述べている．

（2）第2，3章，第4章において，新たに明らかにした事項（新規性・独創的な点）が明確に記述されている．（第5章に，これらの結果がまとめられている）

（3）工学的分野において有効である事項が明確に記述されている．

（4）第2，第3，第4章において，研究方法，実験方法について，他者による再現実験が可能なように，使用装置や実験条件などが詳細に記述されている．

（5）実験・観察・データ解析の結果が正確かつ明確に記述されている．

（6）考察が理論的に展開されて，記述されている．

（7）既発表研究結果や研究成果の参照ならびに引用が公平かつ適切に記述されている．

よって，本論文は「茨城大学大学院理工学研究科における博士学位論文の評価基準」を満たし，博士（工学）の論文いふさわしいと判定された．