Fraunhofer
IPT

FRAUNHOFER INSTITUTE FOR PRODUCTION TECHNOLOGY IPT

VIBROCOOL

VIBRATION-ASSISTED DRILLING OF FRP AND FRP-METAL-STACKS USING SPECIAL COOLING/LUBRICATION STRATEGIES

The demand for high-performance composite structures and hybrid materials is set to increase significantly throughout a range of European industrial sectors. The majority of these components are connected to other predominantly metallic parts, usually via bolted joints or rivets requiring high-quality drill holes. The need to ensure first-class, economical serial production of the burgeoning group of composite-based materials makes it essential to develop more advanced drilling technologies.

To increase the cutting performance of drilling operations involving CFRP (carbon fiber reinforced polymers) and CFRP-Al metal stacks (CFRP with aluminum), a new drilling system and the corresponding process technology was developed and optimized in the "VibroCool" project. This system combines vibration-assisted drilling with the application of cryogenic cooling and optimally designed polycrystalline diamond (PCD) drills. The new technology enables end users to adapt existing machining operations, decrease cutting time and improve workpiece quality.

Modular Approach

The VibroCool project is characterized by a holistic multilevel approach focusing on three interdisciplinary R&D modules and the integration of all of the newly developed technologies to achieve a modified composite-cutting machine.

System Technology

Target: The development and integration of all of the system components required to enable ultrasonic assisted machining and the use of a combined liquid CO_2 and aerosol coolant-lubrication within the "VibroCool" machining platform.

A custom-made machine spindle with a standard HSK-A63 tool interface, a two-channel cooling-lubrication system and a contact-free energy transmission unit suitable for ultrasonic technology was designed and manufactured. The spindle enables high-frequency electrical energy transmission and the internal feed of aerosol and liquid CO_2 at a pressure of 60 bar. The maximum rotational speed is currently 20,000 rpm, with development of a further variant with a 50% higher permissible speed is in progress.

The ultrasonic tool holder developed, has a mechanical and electrical interface to the machine spindle. Two electrical pins are integrated in the flat end of the interface geometry. These transfer the generator energy to the transducer/actuator, where piezo ceramics convert the electrical signals into high frequency mechanical vibration. The transducer is designed to be conical in order to enhance the vibration amplitude and it is equipped with a thermal shrink-fit. A vibration frequency of 32.5 kHz and amplitudes (peak to peak) in the range of 6 to 8 µm were achieved using the newly-developed PCD tools. In addition to providing the ultrasonic tool movement function, the holder enables the combined CO_2-MQL (Minimum Quantity Lubrication) coolant-lubrication technology to be implemented. Since both systems (machine spindle and tool holder) have standard interfaces, the can be easily integrated into virtually any existing or new cutting machine.

In order to increase the cutting performance, new cutting oil compositions have been developed for cryogenic drilling operations conducted on CFRP and CFRP-Al stacks. To this end, the wetting and wear reduction performance at low temperatures were analyzed for different basic components and additives. Ester and saturated fatty alcohols in combination with phosphorus and sulfur additives were found to give the best results for the relevant workpiece materials.

Cutting Tool Technology

Target: Development of optimized polycrystalline diamond drilling tools for ultrasonic assisted drilling of CFRP and CFRP-Al stacks and the possible application of combined liquid CO_2 and aerosol coolant-lubrication.

Different diamond grades, tool tip geometries and other geometrical features have been investigated in terms of drilling CFRP and CFRP-Al stacks. PCD with an average grain size of 10 µm performed best. In the case of CFRP, a double-tipped drill with primary tip angle of 118° and secondary tip angle of 45° achieved the best results and for CFRP-Al drilling, a single tipped drill with chamfered tool corner was the optimal choice. A new internal carbide rod geometry had to be used to implement the planned two-channel cooling-lubrication strategy of the "VibroCool" project. Two spiral bore holes for the aerosol supply and one central bore hole with two exits (y-shape) for the supply of the CO2 were integrated into the rod. The higher rod price was offset by the more efficient tool manufacturing process.

Cutting Process Technology

Target: Process investigations aimed at achieving the best possible system and cutting tool development, but also maximum exploitation of the potential for the "VibroCool" machining platform.

The application of ultrasonic assistance has a clearly measurable effect on the resulting thrust force. With increasing ultrasonic frequency and amplitude, the reduction is more pronounced both for individual CFRP and for stacks. Furthermore, the ultrasonic effect is intensified as tool wear progresses, opening up possibilities for a longer tool life. In the course of the investigations, tool damage at the cutting edge could not be avoided for a standard tool tip geometry in combination with conventional dry machining operations conducted at high cutting speeds, which are a measure of increased machining productivity. Applying ultrasonic vibration with improved tool geometry for CFRP drilling, was found to be an effective way to prevent premature tool damage. The additional application of two-channel MQL (Minimum Quantity Lubrication)-CO_2 technology reduced tool wear significantly, due mainly to the change in fiber cutting behavior, the use of more efficient coolant-lubrication and improved accessibility for the cooling lubrication media, all of which are related to the interrupted cutting process resulting from ultrasonic assistance.

One-shot drilling (drilling different workpiece materials with one single tool and process) of FRP-metal stacks is always associated with deviations between the bore hole diameters generated in FRP and the metal part. These deviations are attributable to the different machining behaviors and the related material resilience. When the entire "VibroCool"-technology is applied, these deviations can be reduced by 70% in comparison with a conventional drilling process using standard cooling and lubrication solution.

Conclusion

The potential of the system and tool technology developed within the framework of all of the investigations completed to date has already been demonstrated. To make full use of this technology and to gain comprehensive process knowledge, further investigations are needed. The "VibroCool" machining platform is, therefore, now available at the research institute. Further advantages of the "VibroCool" technology are the easy transferability to other workpiece materials and processes as well as the possibility of using ultrasonic technology for process monitoring activities, which will be a focus of future research.

Contacts

CHIRON-WERKE GmbH & Co. KG
Kreuzstrasse 75
78532 Tuttlingen
Germany
www.chiron.de

Fraunhofer Institute for Production Technology IPT
Steinbachstrasse 17
52074 Aachen
Germany
www.ipt.fraunhofer.de

SN-Spindeltechnik
Gutenbergstrasse 1
01623 Lommatzsch
Germany
www.sn-spindeltechnik.de

Son-x GmbH
Steinbachstrasse 17
52074 Aachen
Germany
www.son-x.de

Telcon Engineering Ltd.
2 Hamal St., Industrial Park North
Afula 1811001
Israel
www.telconpcd.com

Turkish Aerospace Industries, Inc.
Fethiye Mahallesi, Havacılık Bulvarı No.17
06980 Kazan-Ankara
Turkey
www.tai.com.tr

Zeller+Gmelin GmbH & Co. KG
Schlossstrasse 20
73054 Eislingen
Germany
www.zeller-gmelin.de

SPONSORED BY THE

Federal Ministry of Education and Research

MANAGED BY

PTKA
Project Management Agency Karlsruhe
Karlsruhe Institute of Technology

SPONSORED AND MANAGED BY

TÜBİTAK

MATIMOP מתימו"פ
מרכז התעשייה הישראלית למחקר ופיתוח
Israeli Industry Center For R&D

This research and development project was sponsored by the German Federal Ministry of Education and Research and managed by the PTKA (Project Management Agency Karlsruhe). Sponsorship and management was overseen by Tübitak in Turkey and by the Israeli Industry Center for R&D Matimop in Israel. The responsibility for the content of the publication lies with the authors.