Mondragon Unibertsitatea

5th CIRP CONFERENCE ON SURFACE INTEGRITY (1ST E-conference)

Programme

June 1st-June 5th, 2020

June, 2020

1 INTRODUCTION

It is with great pleasure that we present the programme of the 5th CIRP Conference of Surface Integrity (https://csi2020.mondragon.edu/) organized by Mondragon Unibertsitatea and supported by the International Academy for Production Engineering (CIRP).

Manufacturing processes and surface treatments generating the final functional surfaces of components have influence on surface integrity, and consequently can significantly affect the performance of the finished product. It is therefore of critical importance to select the appropriate process parameters if we want to guarantee the quality of the surface integrity and in-service performance of machined components. This research topic has gained prominence in industry and the academic community in recent decades, and in 2017 the CIRP Council and Liaison Committee Council approved the organization of the 5th CIRP Conference on Surface Integrity to advance understanding of the relationships between manufacturing processes, surface integrity and functional performance. The first CIRP Conference was held in Germany (Bremen University), and the following editions were hosted in UK (Nottingham University, 2014), USA (University of North Caroline at Charlotte, 2016), and China (Tianjin University, 2018).

The 5th CIRP Conference on Surface Integrity was initially planned to take place in Vitoria-Gasteiz in the Basque Country, Northern Spain. However, following the COVID-19 outbreak, the event was moved to a virtual E-Conference, from June 1st to June 5th. As a forum for exchanging knowledge and the latest advances in the field between academics, industrial researchers and engineers the conference fulfills three main goals:

- Contribute to the scientific knowledge of the formation and evolution of surface integrity in various surface processes
- Examine practical case studies and evaluate aspects of surface integrity and functional performance from an industrial point of view
- Discuss advanced manufacturing and measurement technologies that control/improve and evaluate surface integrity.

2 CONFERENCE COMMITTEES

2.1 The 5th CIRP Conference on Surface Integrity Chairmen

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2.2 The 5th CIRP Conference on Surface Integrity Organizing Committee

- Ms. Iratxe Agirre
- Dr. Patxi Xabier Aristimuño
- Dr. Iñaki M. Arrieta
- Ms. Larraitz Azpitarte
- Dr. Mikel Cuesta
- Mr. Aitor Duo
- Dr. Raúl Fernández
- Dr. Ainhara Garay
- Mr. Xabier Lazkano
- Mr. Gorka Ortiz de Zarate
- Mr. Harry Yasir Otalora
- Dr. Mikel Saez de Buruaga
- Mr. Andrés Sela
- Dr. Daniel Soler
- Mr. Denis Soriano
- Ms. Haizea Legorburu
- Ms. Obdulia Velez
- Mr. Julen Zabaleta

Contact details:

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2.3 The 5th CIRP Conference on Surface Integrity Advisory Committee

- Prof. Ekkard Brinksmeier (Germany)
- Prof. Ibrahim S Jawahir (USA)
- Dr. Rachid M'Saoubi (Sweden)

2.4 The 5th CIRP Conference on Surface Integrity Scientific Committee

- Dr. Patxi Xabier Aristimuño (Spain)
- Dr. Pedro J Arrazola (Spain)
- Dr. Yusuf Kaynak (Turkey)
- Dr. Andreas Klink (Germany)

- Dr. Iñaki M. Arrieta (Spain)
- Dr. Helmi Attia (Canada)
- Dr. Vikram Bedekar (USA)
- Dr. Debajyoti Bhaduri (UK)
- Prof. Dirk Biermann (Germany)
- Dr. Giuliano Bissacco (Denmark)
- Prof. Ekkard Brinksmeier (Germany)
- Prof. Stefania Bruschi (Italy)
- Prof. Srinivasan Chandrasekar (USA)
- Prof. Tom Childs (UK)
- Dr. Cédric Courbon (France)
- Dr. Mikel Cuesta (Spain)
- Prof. Matthew Davies (USA)
- Prof. Berend Denkena (Germany)
- Dr. Hongtao Ding (USA)
- Dr. François Ducobu (Belgium)
- Prof. Christopher J Evans (USA)
- Prof. Fengzhou Fang (China)
- Dr. Raúl Fernández (Spain)
- Dr. Ainhara Garay (Spain)
- Dr. Guenael Germain (France)
- Prof. Wit Grzesik (Poland)
- Prof. Han Haitjema (Belgium)
- Prof. Ibrahim S Jawahir (USA)
- Prof. Bernhard Karpuschewski (Germany)
- Dr. Philip Koshy (Canada)
- Prof. Peter Krajnik
- Prof. Ismail Lazoglu (Turkey)
- Prof. Richard Leach (UK)
- Prof. Don A Lucca (USA)
- Dr. Aitor Madariaga (Spain)
- Prof. Shreyes N Melkote (USA)
- Dr. Daniel Meyer (Germany)
- Prof. Nikolaos Michailidis (Greece)
- Dr. Rachid M'Saoubi (Sweden)
- Prof. Jose C Outeiro (France)
- Prof. Tugrul Ozel (USA)
- Prof. Gerard Poulachon (France)
- Dr. Franci Pusavec (Slovenia)
- Prof. Mohammad Rabiey (Switzerland)
- Prof. Joel Rech (France)
- Dr. Mikel Saez de Buruaga (Spain)
- Prof. Enrico Savio (Italy)
- Prof. Volker Schulze (Germany)
- Prof. Luca Seterini (Italy)
- Dr. Daniel Soler (Spain)
- Dr. Sein Leung Soo (UK)
- Prof. Roberto Teti (Italy)
- Prof. Domenico Umbrello (Italy)
- Prof. Jinming Zhou (Sweden)

3 PROGRAMME FORMAT

Industrial and academic experts on surface integrity will deliver four keynote speeches:

- Keynote 1: Dr. Matt Davies, "The Importance of Surface Integrity in the Manufacture of Freeform Optics"
- Keynote 2: Professor Bernhard Karpuschewski, "Surface integrity aspects in gear manufacturing"
- Keynote 3: Professor Joel Rech, ''Surface integrity of parts produced by metal additive processes''
- Keynote 4: Dr. Koldo Ostolaza, '' Surface Integrity oriented machining; the envelope for any optimization attempt for the manufacture of failure critical components''

A total of 92 peer-reviewed papers from 19 countries will be presented at the 5th CIRP Conference on Surface Integrity. These numbers demonstrate an international interest in this field. The technical papers are divided into nine topics:

- Topic 1: Surface Integrity of parts machined with defined cutting edges
- Topic 2: Surface integrity of parts machined with non-defined cutting edges
- Topic 3: Surface integrity produced by non-conventional processes
- Topic 4: Surface integrity generated by mechanical surface treatments
- Topic 5: Finishing and surface integrity of parts produced by additive manufacturing
- Topic 6: Surface integrity of composite materials
- Topic 7: Methods to characterize and control surface integrity properties
- Topic 8: Effect of surface integrity on in-service performance of parts
- Topic 9: Modelling of the surface integrity generated by finishing processes

The E-Conference will start at 09:00 (CET) with the Opening Ceremony and will officially end with the Closing Ceremony on Friday at 16:00 (CET). All authors and attendees will have full access to watch all videos on demand from 08:30 (CTE) on Monday, June 1, until Friday, June 5 at 23:59 (CET). We ask you to respect the copyright of the contributions and your colleagues' work, and **not to record or share any content outside of the E-Conference**.

Participants can add their questions and comments at any time below the video of each presentation, and the authors will answer them. We believe that fruitful discussions help advance knowledge in the field of surface integrity. Additionaly, to stimulate the exchange of ideas, we have scheduled two specific discussion sessions per day, where authors will respond in real time to the questions of the participants from 13:30 (CET) to 16:00 (CET). The organizing committe encourages all attendees to actively participate in these discussions.

With the support of the company ITPAero, we would like you to select The Best Work of the 5th CIRP Conference on Surface Integrity. You can vote on the E-conference website from 4th June at 08:00 (CET) until 5th June 12:00 (CET). The winner will be announced during the closing ceremony of the conference: 5th June, 16:00 (CET). The winner will have the conference fee covered, and the paper and presentation of the best work will be shown on the official website of the conference.

The conference programme is presented below. You can find more information about keynotes in section 4, detailed information about regular presentations in section 5, and all the abstracts can be found in section 6. The titles of the papers are linked to the full paper, which are published in Procedia CIRP.

	June 1st	June 2nd	June 3rd	June 4th	June 5th
9:00-9:30 CET	Opening Ceremony				
			Discussions		
13:30-14:00 CET	Keynote 1	Keynote 2	Keynote 3	Keynote 4	
14:00-16:00 CET	Topic 1_day 1 (10 papers)	Topic 1_day 2 (10 papers)	Topic 1_day 3 (10 papers)	Topic 5 + 6 (11 papers)	Topic 8 (5 papers)
14:00-16:00 CET	Topic 2 (6 papers)	Topic 3 (11 papers)	Topic 4 (5 papers)	Topic 7 (13 papers)	Topic 9 (12 papers)
16:00-16:15 CET					Closure of the conference

4 KEYNOTE TALKS

4.1 Keynote 1: Dr. Matt Davies: ''The Importance of Surface Integrity in the Manufacture of Freeform Optics''

Bio

Ph.D in Aerospace Engineering from Cornell University (1993) and then joined the Manufacturing Engineering Laboratory at NIST. He then came to the University of North Carolina at Charlotte, Center for Precision Metrology, in the spring of 2002. Dr. Davies' research focuses on the study of applied engineering systems and the development of practical applied manufacturing and metrology solutions. In particular, his work at NIST was applied to the stability of high-speed machining processes and on the study of the complex plastic flows of material that occur in the vicinity of the tool in machining processes. He has continued this research at Charlotte where his group developed a high-bandwidth thermal imaging system that produced the highest resolution thermal images of chip formation available at the time. Dr. Davies has pursued two new research areas, metrology and mechanics for the biomedical device industry and the ultraprecision machining of complex optics. He has published several papers on the biomechanics of implants including the first papers on the mechanics of implants for the cervical spine with articulating (ball) joints, and papers on the deformation of the acetabular cup in hip implants and its implications for implant wear. He started a research group focused on the manufacture of freeform and structured optics and is the leader of the Freeform Optics Research Group. Within this group, Dr. Davies was the Director for the Center for Freeform Optics a collaborative consortium with the University of Rochester between 2015 and 2019. During that time, he helped build the Center membership to 18 non-academic members. Dr. Davies has received numerous honors and awards and has more than 75 technical publications and three patents. He is a Fellow of the Fannie and John Hertz Foundation, was awarded the United States Department of Commerce Bronze Medal in 1998, the Society of Manufacturing Engineering, John T. Parsons, Outstanding Young Manufacturing Engineer Award in 2000, the Bonnie Cone Professor for Excellence in Teaching in 2007, the Bank of America Award for Teaching Excellence in 2016 and the North Carolina Board of Governors Teaching Award in 2017. He is currently also conducting research in Adaptive Learning for the teaching of Engineering System Dynamics and has been a Fellow of the CIRP since 2009.

Abstract

Many complex optics are manufactured by ultraprecision machining processes such as multi-axis diamond turning, diamond milling and diamond grinding. Along with computational optical design, multi-degree-of-freedom manufacturing operations and associated equipment have been a driving force behind the development of freeform optics, a disruptive technology in the optics industry. Freeform optics are optics without an axis of symmetry either on or off the optic. Freeform optics allow the nearly arbitrary redirection of light in three dimensions and therefore many axisymmetric designs can be replaced with freeform designs having improved performance or drastically reduced size and part count. Sometimes entirely new optical functions can be realized. However, freeform optics pose significant challenges for manufacturing and metrology. One of the major challenges is maintaining surface integrity using sub-aperture manufacturing methods. In this talk we discuss the effects of surface integrity on optical performance, from the effects of surface roughness and mid-spatial frequency errors to the effect of residual stresses and sub-surface damage. Metrology methods for measuring and characterizing surface integrity will also be discussed. We will give specific examples

ranging from the effect of surface integrity on a freeform all-reflective imaging system to the effects of subsurface damage on transmissive infrared optics.

4.2 Keynote 2: Professor Bernhard Karpuschewski: ''Surface integrity aspects in gear manufacturing''

Bio

Graduated from the University of Hannover, Germany. He received his Ph.D. degree in 1995 with a thesis titled "Micromagnetic surface integrity analysis of case hardened steel workpieces" at the Institute for Production Engineering and Machine Tools (IFW), University of Hannover. From 1995 until April 1999 he worked as chief engineer of the Institute. From May 1999 until October 2000 he accepted a position as Associate Professor at the Keio University, Yokohama (Japan). Following this he was appointed as full professor for production engineering and head of the Laboratory for Production Technology and Organisation (PTO) at the Technical University of Delft (Netherlands), where he worked until March 2005. From April 2005 until August 2017 he worked as full professor for production engineering and managing director of the Institute for Production Technology and Quality Management (IFQ) at the Otto-von-Guericke-University in Magdeburg (Germany). Since September 2017 he has been professor at the University of Bremen (Germany) and director of the Division Manufacturing Technology at the Leibniz Institute for Materials Engineering IWT. Since August 2001 he has been a member of the International Academy for Production Engineering Research (CIRP) and became a fellow in 2005. He is currently Editor-in-chief of the CIRP Journal.

Abstract

Gears are highly loaded components used in many different applications such as automotive, aircraft turbines, ships or wind energy systems. The demand on gears can be summarised by ever rising load capacity on the one hand, and significant noise reduction on the other. Both demands can only be fulfilled by adapted gear finishing processes, generating the best possible macro- and micro- geometry as well as the desired surface integrity state. This keynote presents research work analysing the thermal load on gears during gear hobbing, surface integrity states by different hard gear finishing operations and alternatives to prevent thermal damage in gear manufacturing by adapted process monitoring and fast non-destructive analysing techniques.

4.3 Keynote 3: Professor Joel Rech: ''Surface integrity of parts produced by metal additive processes''

Bio

Joel Rech is Professor at the Ecole Nationale d'Ingénieurs de Saint-Etienne (University of Lyon). He leads a research group of 23 people working on the characterization and modelling of physical phenomena at the tool/workmaterial interface in cutting and superfinishing operations. He made remarkable breakthroughs in numerical modeling of surface integrity induced by cutting and polishing processes (residual stresses, roughness, microstructure) and in modeling of tribological phenomena (friction, wear etc.) of cutting tools. He has supervised 33 PhD theses and has published more than 250 papers that have been cited over 4500 times. He is member of the CIRP and takes part in the editorial committee of 5 international journals. He has been a member of more than 45 scientific committees of international conferences. Since 2014, he has been also Dean for Research in ENISE.

Abstract

Additive manufacturing processes are increasingly gaining importance among mechanical industries. This new field of 3D metal printers covers a wide range of processes using various raw materials (powders, wires, compounds etc.) and different sources of energy (laser, electron beam etc.). It can be stated, however, that the surface integrity (roughness, microstructure, residual stress) of the surfaces generated by additive manufacturing differs considerably from the current state of the art produced by machining and superfinishing processes. This keynote will first aim at summarizing current developments in terms of surface integrity generated by metal additive processes. Then it will present some key finishing processes which can be applied to improve surface integrity depending on the shape of the part and the stiffness of the functional surfaces.

4.4 Keynote 4: Dr. Koldo Osotolaza: '' Surface Integrity oriented machining; the envelope for any optimization attempt for the manufacture of failure critical components''

Bio

Dr. Koldo Ostolaza graduated from the University of Navarra, Spain. He received his Ph.D. in 1992 with the thesis titled "Process optimization and mechanical Behaviour of Liquid Phase Sintered W-Ni-Fe alloys" at the CEIT, University of Navarra. From 1992 until 1996 he worked as a postdoc at the EU Joint Research Center for Advanced Materials in Petten-Holland. In 1996 he joined ITP where he was promoted to the position of Head of Materials & Processes Department in 2000. In that capacity he has further built his expertise in Materials and Process Technologies with a focus on materials methods of manufacture (casting, forging, sintering, powder HIP, SLM, etc.), other manufacturing technologies (machining, welding, chemical processes, coatings, etc.), and their aggregated effect upon material & component performance. He has worked with a wide variety aerospace materials such as superalloys, Ti alloys, steels. While in industry, he has kept a connection with Academia. He has been co-director of 2 PhD theses. He has participated in 12 PhD Tribunals and has contributed to 38 papers. Throughout his professional career, he has been involved in more than 30 R+T projects, and in a leadership role in 4 European projects within JTI-CS1 and CS2 calls.

Abstract

Machining is a relevant process for component manufacture and as such, it is under the industry pressure to reduce costs while decreasing its environmental footprint. As a result, new machining technologies are coming along which keep their competitive edge to "shape" materials.

In the case of failure critical components, other characteristics brought by machining play also a key role. These are captured under the generic term surface integrity, which compiles a range of characteristics such as (micror)roughness, (sub)surface damage, residual stresses etc. Their relevance relies upon their combine effect upon the fatigue and failure response engineers are looking for at the design stage. The achievement of those surface related characteristics which up to now, have been achieved following a trial-and-error approach, underpins the great potential machining technologies have alongside surface functionalization.

The further exploitation of this will require doing things differently. We may need to compile and post process information we already have. We may need to generate it anew. We should challenge the basic physical understanding we have about Machining and the interactions that take place between tool and metal piece. Process modelling may help. We need the concourse of different knowledge; e.g. manufacturing, materials science, stress engineering and the inputs from IoT, data science, NDT´s etc. In the absence of a single path, some principles will be highlighted and discussed together with the potential roadmaps and expected outcomes. The journey will be rather long and should allow cashing

quick wins. But this effort should also allow helping to change the perception young technologists may have about machining as a “too conventional” technology so that it can capture their intellectual attention whilst keeping its competitive edge.

5 DETAILED PROGRAMME OF REGULAR PRESENTATIONS

5.1 Topic 1: Surface integrity of parts machined with defined cutting edge

ID	Title	Authors	Q&A session
PROCIR-D-19-01338R2	**Micro milling of areal material measures – Study on surface generation for different up and down milling strategies**	**Katja Klauer**; Matthias Eifler; Benjamin Kirsch; Jörg Seewig; Jan C. Aurich	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01341R2	**Influence of the cutting parameters on the surface properties in turning of a thermally sprayed AlCoCrFeNiTi coating**	Benjamin Clauß; **Hendrik Liborius**; Thomas Lindner; Martin Löbel; Andreas Schubert; Thomas Lampke	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01344R2	**Process behaviour of micro-textured CVD diamond thick film cutting tools during turning of Ti-6Al-4V**	Eckart Uhlmann; **Danny Schröter**	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01347R2	**The Effect of Milling Parameters on Surface Properties of Additively Manufactured Inconel 939**	**Ceren Şen**; Levent Subaşı; Ozan Can Ozaner; Akın Orhangül	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01348R2	**Characterization of the subsurface properties of metastable austenitic stainless steel AISI 347 manufactured in a two-step turning process**	**Hendrik Hotz**; Marek Smaga; Benjamin Kirsch; Tong Zhu; Tilmann Beck; Jan C. Aurich	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01356R2	**Influence of the process parameters and forces on the bore sub-surface zone in BTA deep-hole drilling of AISI 4140 and AISI 304 L**	**Robert Schmidt**; Simon Strodick; Frank Walther; Dirk Biermann; Andreas Zabel	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01361R2	**Investigation on work hardening phenomenon in turning Inconel 718 with chamfered inserts considering thermal-mechanical loads**	**Kejia Zhuang**; Chen Hu; Jinming Zhou; Lin Ru Peng	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01363R3	**Effect of cutting edge microgeometry on surface roughness and white layer in turning AISI 52100 steel**	**Weiwei Zhang**; Kejia Zhuang	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01371R3	**Experimental study of the connection between process parameters, thermo-mechanical loads and surface integrity in machining Inconel 718**	**Thorsten Augspurger**; Markus Meurer; Hui Liu; Patrick Mattfeld; Thomas Bergs	June 1st (14:00 -16:00, CET)

PROCIR-D-19-01381R2	**Initial investigation on Surface Integrity when Machining Inconel 718 with Conventional and Electrostatic Lubrication**	**Andrea De Bartolomeis**; Stephen T Newman; Alborz Shokrani	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01384R3	**Graphene Nanoplatelets-Assisted Minimum Quantity Lubrication In Turning To Enhance Inconel 718 Surface Integrity**	**Rachele Bertolini**; Gong Le; Andrea Ghiotti; Stefania Bruschi	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01385R2	**Influence of different cooling strategies during hard turning of AISI 52100 - part I: thermo-mechanical load, tool wear, surface topography and manufacturing accuracy**	**Stephan Basten**; Benjamin Kirsch; Werner Ankener; Marek Smaga; Tilmann Beck; Julian Uebel; Jörg Seewig; Jan C. Aurich	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01394R3	**Experimental identification of a surface integrity model for turning of AISI4140**	**Benedict Stampfer**; David Böttger; Daniel Gauder; Frederik Zanger; Benjamin Häfner; Benjamin Straß; Bernd Wolter; Gisela Lanza; Volker Schulze	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01396R2	**Complementary Machining: Effect of tool types on tool wear and surface integrity of AISI 4140**	**Jannik Schwalm**; Michael Gerstenmeyer; Frederik Zanger; Volker Schulze	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01399R3	**Milling parameter and tool wear dependent surface quality in micro-milling of brass**	**Stephan Dehen**; Eric Segebade; Michael Gerstenmeyer; Frederik Zanger; Volker Schulze	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01407R2	**Evolution of the surface integrity while turning a fillet radius in a martensitic stainless steel 15-5PH**	**Maxime Dumas**; Frédéric Valiorgue; Guillaume Kermouche; Alexis Van Robaeys; Ugo Masciantonio; Alexandre Brosse; Habib Karaouni; Jöel Rech	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01408R2	**Impact of cutting tool wear on residual stresses induced during turning of a 15-5 PH stainless steel**	**Florent Clavier**; Frédéric Valiorgue; Cédric Courbon; Maxime Dumas; Joël Rech; Alexis Van Robaeys; Fabien Lefebvre; Alexandre Brosse; Habib Karaouni	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01409R3	**Effects on surface and peripheral zone during single lip deep hole drilling**	Robert Wegert; **Vinzenz Guski**; Siegfried Schmauder; Hans-Christian Möhring	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01421R2	**Influence of different cooling strategies during hard turning of AISI 52100– part II: characterization of the surface and near surface microstructure morphology**	**Werner Ankener**; Julian Uebel; Stephan Basten; Marek Smaga; Benjamin Kirsch; Jörg Seewig; Jan C. Aurich; Tilmann Beck	June 2nd (14:00 -16:00, CET)

PROCIR-D-19-01429R2	**Adsorption and reaction layers when turning AISI 304 using various cooling strategies**	**Stephan Basten**; Benjamin Kirsch; Rolf Merz; Michael Kopnarski; Hans Hasse; Jan C. Aurich	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01432R3	**Investigation on residual stresses in milling of Ti-6Al-4V for both rake and flank application of different MWF strategies**	**Anshab kummamkandath**; Arnaud Duchosal; Antoine Morandeau; René Leroy	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01433R3	**Influence of built up edge on the surface topography of Ti-15Mo**	Denny Paris; Leonildo Pivotto; Carlos Eiji Hirata Ventura; **Armando Antonialli**	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01434R2	**The effect of cutting edge geometry, nose radius and feed on surface integrity in finish turning of Ti-6Al4V**	**Ian Brown**; Julius Schoop	June 3rd (14:00 -16:00, CET)
PROCIR-D-19-01437R2	**Machining-induced surface integrity of holes drilled in lead-free brass alloy**	**Nima Zoghipour**; Emre Tascioglu; Gokhan Atay; Yusuf Kaynak	June 3rd (14:00 -16:00, CET)
PROCIR-D-19-01450R2	**Surface topography analysis of ball end milled tool steel surfaces**	**Francesco Giuseppe Biondani**; Giuliano Bissacco; Hans Nørgaard Hansen	June 3rd (14:00 -16:00, CET)
PROCIR-D-19-01453R2	**Effect of progressive tool wear on the functional performance of micro milling process of injection molding tool**	Ali Davoudinejad; **Dongya Li**; Yang Zhang; Guido Tosello	June 3rd (14:00 -16:00, CET)
PROCIR-D-19-01456R2	**The influence of single-channel liquid CO_2 and MQL delivery on surface integrity in machining of Inconel 718**	**Luka Sterle**; Franci Pušavec; Dinesh Mallipeddi; Peter Krajnik	June 3rd (14:00 -16:00, CET)
PROCIR-D-19-01717R2	**Surface roughness response to drilling of Ti-5Al-5Mo-5V-3Cr using Ti-Al-N PVD coated and uncoated WC/Co tools**	**Alex David Graves**; Pete Crawforth; Susanne Norgren; Martin Jackson	June 3rd (14:00 -16:00, CET)
PROCIR-D-20-00002R1	**Effect of tool coatings on surface grain refinement in orthogonal cutting of AISI 4140 steel**	**German Gonzalez**; Marcel Plogmeyer; Frederik Zanger; Saskia Biehl; Günter Bräuer; Volker Schulze	June 3rd (14:00 -16:00, CET)

5.2 Topic 2: Surface integrity of parts machined with non-defined cutting edge

ID	Title	Authors	Q&A session
PROCIR-D-19-01353R3	Surface integrity in micro-grinding of Ti6Al4V considering the specific micro-grinding energy	**Mohammadali Kadivar**; Bahman Azarhoushang; Amir Daneshi; Peter Krajnik	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01392R2	Residual stress change in multistage grinding	**Ewald Kohls**; Robert Zmich; Carsten Heinzel; Daniel Meyer	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01416R3	Investigation on Surface Integrity of Steel DIN 100Cr6 by Grinding Using CBN Tool	**Mohammad Rabiey**; Pascal Maerchy	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01422R2	Development of surface residual stress and surface state of 42CrMo4 in multistage grinding	Florian Borchers; Heiner Meyer; Carsten Heinzel; **Daniel Meyer**; Jérémy Epp	June 1st (14:00 -16:00, CET)t
PROCIR-D-19-01445R3	Surface Integrity of Powder Metallurgy Superalloy FGH96 Affected by Grinding with Electroplated CBN Wheel	Ziming Wang; **Xun Li**; Haining Wang; Jianhua Yu; Rufeng Xu	June 1st (14:00 -16:00, CET)
PROCIR-D-19-01447R3	Towards the prediction of surface roughness induced by the belt finishing process: influence of the material on the roughness reduction rate	**Frédéric Cabanettes**; Oussama Cherguy; Cédric Courbon; Axel Giovenco; Sangil Han; Joël Rech	June 1st (14:00 -16:00, CET)

5.3 Topic 3: Surface integrity produced by non-conventional processes

ID	Title	Authors	Q&A session
PROCIR-D-19-01334R2	Fabrication of Interference Textures on Cemented Carbides Using Nanosecond and Femtosecond Laser Pulses	**Shiqi Fang**; Daniel W. Müller; Christiane Rauch; Yanping Cao; Frank Mücklich; Luis Llanes; Dirk Bähre	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01340R2	Impact of ultrasonic assisted cutting of steel on surface integrity	Melanie Willert; **Tjarden Zielinski**; Kai Rickens; Oltmann Riemer; Bernhard Karpuschewski	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01346R3	Surface integrity comparison of wire electric discharge machined Inconel 718 surfaces at different machining stabilities	**Abhilash P. M.**; Chakradhar D	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01379R2	Surface Microstructuring of Steel Components for CVD Diamond Coating by Ultrasonic Vibration Superimposed Face Milling using Tailored Tools	**Richard Börner**; Maximilian Göltz; Thomas Helmreich; Andreas Schubert; Stefan Rosiwal	June 2nd (14:00 -16:00, CET)

PROCIR-D-19-01380R3	**Laser finishing of polycrystalline diamond as strengthening mechanism**	**Manuela Pacella**	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01390R2	**Influence of lubrication condition on the surface integrity induced during drag finishing**	**Irati Malkorra**; Ferdinando Salvatore; Joël Rech; Pedro José Arrazola; Joffrey Tardelli; Aude Mathis,	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01415R2	**Surface Integrity Analysis of Ceramics Machined by Wire EDM Using Different Trim Cut Technologies**	Thomas Bergs; **Marcel Olivier**; Andrea Gommeringer; Frank Kern; Andreas Klink	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01449R3	**Fabrication of mechanically enhanced superhydrophobic surface using nanosecond laser-based high-throughput surface nanostructuring (nHSN)**	Qinghua Wang; Avik Samanta; Amanuel Hailu; Scott K. Shaw; **Hongtao Ding**	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01451R3	**Experimental Study on Electrochemical Machining with Electrolyte Confined by Absorption Material**	**Wataru Natsu**; Junfeng He; Yu Iwanaga	June 2nd (14:00 -16:00, CET)
PROCIR-D-19-01454R2	**Manufacturing of three-dimensional optical functional surfaces by diamond engraving of RSA 905**	**Dongya Li**; Yang Zhang; Xinquan Zhang; Dennis Neo; Ali Davoudinejad; Guido Tosello	June 2nd (14:00 -16:00, CET)
PROCIR-D-20-00001R1	**Experimental Investigation on Process Signature for EDM Processes**	Thomas Bergs; **Mehnoush Mohammadnejad**; Maximillian Witteler; Lukas Heidemmans; Andreas Klink	June 2nd (14:00 -16:00, CET)

5.4 Topic 4: Surface integrity generated by mechanical surface treatments

ID	Title	Authors	Q&A session
PROCIR-D-19-01337R2	**Laser peening of 420 martensitic stainless steel using ultrashort laser pulses**	**Niroj Maharjan**; Zhenyuan Lin; Dennise Tanoko Ardi; Lingfei Ji; Mighui Hong	June 3rd (14:00 -16:00, CET)
PROCIR-D-19-01386R2	**Data Driven Optimization of Vibropeening**	Abhay Gopinath; **Wai Luen Chan**; A. Senthil Kumar	June 3rd (14:00 -16:00, CET)
PROCIR-D-19-01405R2	**Sequential multistage deep rolling under varied contact conditions**	**Matthias-Alexander Hettig**; Daniel Meyer	June 3rd (14:00 -16:00, CET)
PROCIR-D-19-01463R2	**Robotic hammer peening-induced martensite in austenitic steels: Spatial distributions of plastic deformation and phase transformation**	**Hongfei Liu**; Chee Kiang Ivan Tan; Yuefan Wei; Guo Wei Lim; Wei Shin Cheng; Niroj Maharjan	June 3rd (14:00 -16:00, CET)

PROCIR-D-20-00003R1	**Influence of subsurface properties on the application behavior of hybrid components**	Bernd Breidenstein; Berend Denkena; **Vannila Prasanthan**; Kolja Meyer	June 3rd (14:00 -16:00, CET)

5.5 Topic 5: Finishing and surface integrity of parts produced by additive manufacturing

ID	Title	Authors	Q&A session
PROCIR-D-19-01373R2	**Surface and sub-surface integrity of Ti-6Al-4V components produced by selective electron beam melting with post-build finish machining**	**Thomas Childerhouse**; Everth Hernandez-Nava; Rachid M'Saoubi; Nikolaos Tapoglou; Martin Jackson	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01388R2	**Surface integrity in abrasive flow machining (AFM) of internal channels created by selective laser melting (SLM) in different building directions**	**Sangil Han**; Ferdinando Salvatore; Joël Rech; Julien Bajolet; Joel Courbon	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01393R2	**Wire electrical discharge polishing of additive manufactured metallic components**	Jibin Boban; **Afzaal Ahmed**; M Azizur Rahman; Mustafizur Rahman	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01418R2	**Surface Integrity of Machined Electron Beam Melted Ti6Al4V Alloy Manufactured with Different Contour Settings and Heat Treatment**	**Dinesh Mallipeddi**; Lars-Erik Rännar; Sinuhe Hernandez; Emil Strandh; Peter Krajnik; Tina Hajali; Lars Nyborg; Alex Bergstrom	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01420R3	**Selection of machining condition on surface integrity of additive and conventional Inconel 718**	**Sasidharan Periane**; Arnaud Duchosal; Sébastien Vaudreuil; Hicham Chibane; Anthony Xavior; Antoine Morandeau; René Leroy	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01426R2	**On the surface integrity of additive manufactured and post-processed AlSi10Mg parts**	**Debajyoti Bhaduri**; Pavel Penchev; Stefan Dimov; Khamis Essa; Luke N Carter; Catalin I Pruncu; Jun Jiang; Daniele Pullini	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01428R2	**Analysis of the surface integrity induced by face milling of Laser Metal Deposited Ti-6Al-4V**	**Achref Kallel**; Arnaud Duchosal; Hedi Hamdi; Guillaume Altmeyer; Antoine Morandeau; Stephane Meo	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01440R2	**Surface integrity induced in machining additively fabricated nickel alloy Inconel 625**	Lihang Yang, Kaushalendra Patel, Krzysztof Jarosz, **Tugrul Özel**	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01455R3	**Drilling process and resulting surface properties of Inconel 718 alloy fabricated by Selective Laser Melting Additive Manufacturing**	**Yusuf Karabulut**; Yusuf Kaynak	June 4th (14:00 -16:00, CET)

5.6 Topic 6: Surface integrity of composite materials

ID	Title	Authors	Q&A session
PROCIR-D-19-01411R2	**Multilayer structure dependent performance behaviour of CVD diamond thin film drilling tools during CFRP machining**	Eckart Uhlmann; **Daniel Hinzmann**; Walter Reimers; Katrin Böttcher	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01424R2	**Study of the machining induced damage in UD-CFRP laminates with various fibre orientations: FE assessment**	**Fernando Cepero-Mejías**; Kevin Kerrigan; Jose Curiel-Sosa; Vaibhav Phadnis	June 4th (14:00 -16:00, CET)

5.7 Topic 7: Methods to characterise and control surface integrity properties

ID	Title	Authors	Q&A session
PROCIR-D-19-01326R2	**Surface drag analysis after Ti-6Al-4V orthogonal cutting using grid distortion**	**Andres Sela**; Gorka Ortiz-de-Zarate; Daniel Soler; Patxi Aristimuño; Guénaël Germain; Pedro José Arrazola; François Ducobu	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01350R2	**Ductile-brittle transition detection in scratching of single crystal silicon using charged particle emissions**	**Arun Veerabagu Sankara Subramanian**; Chirag Alreja; Sathyan Subbiah	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01357R3	**3D FIB/FESEM tomography of grinding-induced damage in WC-Co cemented carbides**	Jing Yang; Joan J Roa; Magnus Odén; Mats Johansson-Jõesaar; **Luis Llanes**	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01362R3	**Experimental approach for a grinding burn in-process inspection system based on Eddy Current**	**Jose Luis Lanzagorta**; Lander Urgoiti; David Barrenetxea; Paula Ruiz Vázquez; Jose Alberto Sánchez	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01366R3	**Sensorization of Shot Peening for Process Monitoring: Media Flow Rate Control for Surface Quality**	**Augustine Teo**; Yicheng Jin; Kunal Ahluwalia; Ampara Aramcharoen	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01368R3	**Surface integrity of additive manufacturing parts: a comparison between optical topography measuring techniques**	**Wilson Tato**; Liam Blunt; Iñigo Llavori; Andrea Aginagalde; Andrew Townsend; Alaitz Zabala	June 4th (14:00 -16:00, CET)

PROCIR-D-19-01372R2	**In-process workpiece displacement measurements under the rough environments of manufacturing technology**	**Andreas Tausendfreund**; Dirk Stöbener; Andreas Fischer	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01377R2	**An approach for a reliable detection of grinding burn using the Barkhausen noise multi-parameter analysis**	**Daniel Sackmann**; Jonas Heinzel; Bernhard Karpuschewski	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01400R3	**Non-destructive detection of machining-induced white layers in ferromagnetic alloys**	**Matthew Brown**; Hassan Ghadbeigi; Pete Crawforth; Rachid M'Saoubi; Andrew Mantle; Jamie McGourlay; David Wright	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01413R3	**Influence of process chains with thermal, mechanical and thermomechanical impact on the surface modifications of a grind-strengthened 42CrMo4 steel**	**Lisa Ehle**; Rebecca Strunk; Florian Borchers; Alexander Schwedt; Brigitte Clausen; Joachim Mayer	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01414R2	**Method for process monitoring of surface layer changes in turning of aluminium alloys using tools with a flank face chamfer**	Hendrik Liborius; **Thomas Junge**; Thomas Mehner; Andreas Nestler; Andreas Schubert; Thomas Lampke	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01430R2	**An optical method to determine the strain field on micro samples during electrohydraulic forming**	**Dirk Stöbener**; Gabriela Alexe; Lasse Langstädtler; Marius Herrmann; Christian Schenck; Andreas Fischer	June 4th (14:00 -16:00, CET)
PROCIR-D-19-01438R4	**Development of a Methodology for Strain Field Analysis during Orthogonal Cutting**	**Markus Meurer**; Thorsten Augspurger; Berk Tekkaya; Daniel Schraknepper; André Pontes Lima; Thomas Bergs	June 4th (14:00 -16:00, CET)

5.8 Topic 8: Effect of surface integrity on in-service performance of parts

ID	Title	Authors	Q&A session
PROCIR-D-19-01339R2	**Influence of residual stress depth distribution on lifecycle behaviour of AISI4140**	**Kolja Meyer**; Berend Denkena; Bernd Breidenstain; Alexandre Mendes Abrao	June 5th (14:00 -16:00, CET)
PROCIR-D-19-01427R2	**Analysis of the Influence of Surface Integrity of Cemented Carbides Machined by Sinking EDM on Flexural Fatigue**	Thomas Bergs; **Timm Petersen**; Ugur Tombul; Andreas Klink	June 5th (14:00 -16:00, CET)
PROCIR-D-19-01444R2	**Machining for an increased fatigue life for a Ti-6Al-4V ELI component**	**Pieter Andries le Roux**; Rudolph F. Laubscher; Andreas Schubert	June 5th (14:00 -16:00, CET)

PROCIR-D-19-01452R3	**Comparison of Additively Manufactured vs. Conventional Maraging Steel in Corrosion-Fatigue Performance after various surface treatments**	**Emmanouil Bouzakis**; Apostolos Arvanitidis; Fotis Kazelis; Georgios Maliaris; Nikolaos Michailidis	June 5th (14:00 -16:00, CET)
PROCIR-D-19-01705R2	**Load Capacity of Rolling Contacts Manufactured by Wire EDM Turning**	Thomas Bergs; **Ugur Tombul**; Dieter Mevissen; Andreas Klink; Jens Brimmers	June 5th (14:00 -16:00, CET)

5.9 Topic 9: Modelling of the surface integrity generated by finishing processes

ID	Title	Authors	Q&A session
PROCIR-D-19-01336R2	**Prediction of Surface Residual Stress on Titanium Alloy generated by Belt Grinding using Molecular System Dynamics**	Yun Huang; Shuai Liu; **Guijian Xiao**; Yi He; Wenxi Wang; Wentao Dai	June 5th (14:00 -16:00, CET)
PROCIR-D-19-01364R2	**Modeling and analysis of residual stress in dynamic orthogonal cutting**	Zhihao Deng; Xiaoming Zhang; **Zhengyan Yang**; Dong Zhang; Han Ding	June 5th (14:00 -16:00, CET)
PROCIR-D-19-01365R4	**Experimental and numerical study of the subsurface deformation and residual stress during the roller burnishing process**	**Dong Zhang**; Xiaoming Zhang; Han Ding	June 5th (14:00 -16:00, CET)
PROCIR-D-19-01367R2	**A physically based model of *Ti6Al4V* turning process to predict surface integrity improvements**	**Sergio Rinaldi**; Giovanna Rotella; Domenico Umbrello; Luigino Filice	June 5th (14:00 -16:00, CET)
PROCIR-D-19-01378R3	**Forming mechanisms based simulation and prediction of grinding surface roughness for abrasive belt rail grinding**	Chaoyue Zhao; Jianyong Li; **Wenxi Wang**	June 5th (14:00 -16:00, CET)
PROCIR-D-19-01395R3	**Determination of residual stresses in processes with multiple thermal loads**	**Julian Vorspohl**; Friedhelm Frerichs; Sebastian Schneider; Matthias Meinke; Wolfgang Schroeder; Andreas Klink; Thomas Lübben	June 5th (14:00 -16:00, CET)
PROCIR-D-19-01401R3	**A simulation-based analysis of internal material loads and material modifications in multi-step deep rolling**	**Tobias Kinner-Becker**; Jens Sölter; Bernhard Karpuschewski	June 5th (14:00 -16:00, CET)
PROCIR-D-19-01404R3	**Influence of Initial Microstructure on Manufacturing Processes with Thermal Loads accompanied by Hardening**	**Friedhelm Frerichs**; Thomas Lübben	June 5th (14:00 -16:00, CET)
PROCIR-D-19-01439R2	**Residual stresses prediction in machining of Inconel 718 superalloy using a constitutive model considering the state of stress**	**Francisco A. V. da Silva**; Lamice A. Denguir; José C. Outeiro	June 5th (14:00 -16:00, CET)

PROCIR-D-19-01443R2	**Sensitivity analysis of the input parameters of a physical based ductile failure model of Ti-6Al-4V for the prediction of surface integrity**	**Gorka Ortiz-de-Zarate**; Andres Sela; Aitor Madariaga; Thomas H. C. Childs; Pedro José Arrazola	June 5th (14:00 -16:00, CET)
PROCIR-D-19-02217R3	**Finite element simulations of the material loads and residual stresses in milling utilizing the CEL method**	**Andrey Vovk**; Jens Sölter; Bernhard Karpuschewski	June 5th (14:00 -16:00, CET)
PROCIR-D-20-00053R2	**Predicting the induction hardened case in 42CrMo4 cylinders**	**Maialen Areitioaurtena**; Unai Segurajauregi; Iker Urresti; Martin Fisk; Eneko Ukar	June 5th (14:00 -16:00, CET)

6 ABSTRACTS OF THE PRESENTATIONS

6.1 Topic 1: Surface integrity of parts machined with defined cutting edge

ID	Title	Authors	Q&A session
PROCIR-D-19-01338R2	**Micro milling of areal material measures – Study on surface generation for different up and down milling strategies**	**Katja Klauer**; Matthias Eifler; Benjamin Kirsch; Jörg Seewig; Jan C. Aurich	June 1st (14:00 -16:00, CET)
Ball end micro milling is a suitable process for the manufacturing of freeform surfaces and therefore appropriate for the manufacturing of material measures according to ISO 25178-70. In previous studies of the authors, ball end micro milling of areal material measures with specified microstructures was experimentally investigated and the influence of the cutting parameters, as well as the influence of the control dataset parameters and the tilt angle were systematically analyzed. The influences of the surface generation strategy (up or down milling) and the chosen tool path on the surface quality of the manufactured structure are investigated experimentally in this study. For this purpose, a full factorial experimental design is created in which two different areal material measure geometries (ACS and AFL as described in ISO 25178-70) are examined applying two different tools in two different surface generation strategies (up or down milling). In addition, two different cases per surface generation strategy are tested: the tool is retracted in the milled groove (case 1: reverse movement with engaged tool) or the tool is lifted between two paths (case 2: reverse movement without tool contact). On the basis of these two cases it is possible to evaluate how the repeatability of the z-axis (case 1) or the smaller short-wavelength roughness due to the second cut (case 2) influences the surface quality of the milled structure. In addition, a meander-shaped tool path is tested as reference: the tool moves alternately in up and down milling direction without lifting from the workpiece. The meander-shaped tool path is the most time-efficient and was applied in previous studies. As a result, information on the influence of the milling strategy on dimensional accuracy and surface roughness is provided. The quality of the manufactured surfaces is compared both quantitatively (based on areal surface texture parameters) and qualitatively (measured topography compared to nominal geometry).			
PROCIR-D-19-01341R2	**Influence of the cutting parameters on the surface properties in turning of a thermally sprayed AlCoCrFeNiTi coating**	Benjamin Clauß; **Hendrik Liborius**; Thomas Lindner; Martin Löbel; Andreas Schubert; Thomas Lampke	June 1st (14:00 -16:00, CET)
High-entropy alloys (HEAs) represent a comparably novel class of materials composed of approximately equimolar fractions of at least four chemical elements. Applied by thermal spraying, the material can be used as a wear protection layer. In order to achieve predefined functional surface properties, finish machining of the applied layers is typically necessary. In this context, the scientific field of HEA machining is hardly opened up requiring intensified research activities. Accordingly, cutting experiments based on turning are addressed. The specimens are represented by cylindrical sections of the aluminium wrought alloy type EN AW-5754 thermally spray coated with a HEA of the composition AlCoCrFeNiTi. For the experimental investigations, indexable inserts with a standardised geometry CCGW 09T304 are used. Especially, the influence of the cutting speed and the feed on the resulting surface properties is focused, while the depth of cut is kept unchanged throughout the cutting tests. The geometrical properties of the machined surface of the sprayed coating are characterised by roughness parameters, valley void volume and a qualitative assessment using scanning electron microscopy (SEM). Residual stresses in the surface layer are determined			

by X-ray diffraction analysis using sin2 Ψ method. The results show a decrease of Rz, Rvk, and Vvv with an increase of the cutting speed. This is primarily attributed to a decreased proportion of pulled-out coating material. Additionally, compressive residual stresses are determined in the axial direction. The absolute values of these stresses decrease with an increasing cutting speed. The presented research expands the field of HEA machining with geometrically defined cutting edges. Further research activities should address a deeper understanding of the mechanisms in machining of HEAs. Moreover, the findings should be transferred to cutting processes with rotating tools such as milling and drilling.

PROCIR-D-19-01344R2	**Process behaviour of micro-textured CVD diamond thick film cutting tools during turning of Ti-6Al-4V**	Eckart Uhlmann; **Danny Schröter**	June 1st (14:00 -16:00, CET)

Currently, an efficient machining of high-performance materials, such as titanium alloy Ti-6Al-4V, represents a challenge in manufacturing. For the reduction of high cutting temperatures, micro-textured CVD diamond thick film cutting tools establish new potentials regarding the process productivity. The application of micro-textures allows a reduced contact area between chip and tool in order to decrease the generation of heat. Furthermore, a direct application of lubricant into the cutting zone is possible. The present study investigates the influence of micro-textured CVD diamond thick film cutting tools on the resulting process forces, chip formation as well as maximum cutting volumes during turning process. Part of the investigations was a variation of micro-texture trajectory with micro-textures parallel to the major cutting edge, perpendicular to the bisector of corner angle ε and curved along the cutting edge. The analyses showed that both positive and negative effects occur using micro-textures. The forces can be reduced by 14 % whereas the use of micro-textures leads to higher feed forces Ff by 21 % as well as an additional notch effect in the micro-texture bottom.

PROCIR-D-19-01347R2	**The Effect of Milling Parameters on Surface Properties of Additively Manufactured Inconel 939**	**Ceren Şen**; Levent Subaşı; Ozan Can Ozaner; Akın Orhangül	June 1st (14:00 -16:00, CET)

This research focuses on experimental studies on Inconel 939, which is a material used in aerospace applications where more commonly preferred Inconel 718 is not usable due to high-temperatures. Inconel 939 parts are often wrought or cast, while the studies are usually focused on durability and weldability of the material. There are studies that uses additive manufacturing method for complex parts; however, these parts need secondary processes to provide tight geometrical tolerances. A first-time study of machining on additively manufactured Inconel 939 material is presented in this paper with the focus on surface properties. Inconel 939 samples were manufactured by Direct Metal Laser Sintering (DMLS) process. Milling operations were performed on these samples with different cutting speeds and feeds to understand the effect on surface roughness and hardness. Design of experiments were performed such that the specimens were machined as “as-built” and heat treated (HT) conditions. The cutting direction according to build direction was also taken into account. The results showed that the cutting parameters, heat treatment condition and build direction have an effect on the surface properties.

PROCIR-D-19-01348R2	**Characterization of the subsurface properties of metastable austenitic stainless steel AISI 347 manufactured in a two-step turning process**	**Hendrik Hotz**; Marek Smaga; Benjamin Kirsch; Tong Zhu; Tilmann Beck; Jan C. Aurich	June 1st (14:00 -16:00, CET)

At high mechanical loads and below martensite deformation temperature, metastable austenitic stainless steels undergo a deformation-induced phase transformation from γ-austenite to ε- and/or α’-martensite. During cryogenic turning, this can be exploited in order to realize subsurface hardening, thus avoiding

a separate hardening process. An increase of the cutting edge radius, the chamfer angle and the feed rate leads to higher passive forces, consequently a more pronounced phase transformation and ultimately to a higher microhardness. However, increasing these input variables also results in a significant increase in surface roughness. In order to eliminate this conflict of objectives between subsurface properties and surface topography, a two-step turning process is proposed. In the first process step a pronounced phase transformation and high plastic deformation of retained austenite by means of heavily chamfered tools, very high feed rates and precooling are realized in the workpiece subsurface. In the second process step, the pronounced roughness peaks are removed, while maintaining the desired subsurface properties achieved in the first step and even increasing the phase fraction of deformationinduced α'-martensite at and near the surface. In the presented study, the surface and subsurface of workpieces manufactured applying this approach were examined. The residual stresses and the phase fraction of γ-austenite, deformation-induced ε-martensite and α'-martensite after the first and second process step were measured by means of x-ray diffraction.

PROCIR-D-19-01356R2	**Influence of the process parameters and forces on the bore sub-surface zone in BTA deep-hole drilling of AISI 4140 and AISI 304 L**	**Robert Schmidt**; Simon Strodick; Frank Walther; Dirk Biermann; Andreas Zabel	June 1st (14:00 -16:00, CET)

The relationship between the cutting speed, the feed, the resulting process forces during the BTA deep hole-drilling process and the functional properties in the bore sub-surface zone of AISI 4140 and AISI 304 L is analysed. Due to the asymmetric design of the drill head radial forces occur which are supported through guide pads on bore surface. The result is an inner force flow inside the tool that affects a self-guiding effect during the drilling process. Due to this process the bore (sub-)surface zone is impinged with thermal and mechanical loads resulting in hardening, structural changes in microstructure and the occurrence of residual stresses, which can influence the fatigue strength, service life or reliability of the part. Residual stresses are measured using the magnetic Barkhausen noise method. Understanding the relationship between the process forces and functional properties in the bore sub-surface zone is essential for a following process control in order to generate defined bore sub-surface zones.

PROCIR-D-19-01361R2	**Investigation on work hardening phenomenon in turning Inconel 718 with chamfered inserts considering thermal-mechanical loads**	**Kejia Zhuang**; Chen Hu; Jinming Zhou; Lin Ru Peng	June 1st (14:00 -16:00, CET)

Work hardening layer on and beneath the machined surface is one of the key factors that affects the performance and service time of the final component. However, the mechanism of the work hardening generation and its behavior are still great challenges and open issues to the academic and industry. In this paper, an investigation of the work hardening layer generated by chamfered tools is conducted based on the simulation and experimental study with the consideration of cutting force and temperature. Series of cutting tests and simulations using various edge preparation and feed rate are conducted to obtain the cutting forces, temperature and micro hardness profiles. Then, models for cutting force prediction and temperature simulation are used to reveal the generation of thermal-mechanical loads during the cutting operation. The effect of cutting edge preparation and feed rate on the generation of cutting force, temperature and work hardening was studied. The results indicate that the depth of work hardening layer can achieve to more than 60 μm under the given cutting conditions with chamfered tools. The role of feed rate and chamfer length playing in the generation of work hardening behavior in machining Inconel 718 was also discussed in the paper.

PROCIR-D-19-01363R3	**Effect of cutting edge microgeometry on surface roughness and white layer in turning AISI 52100 steel**	**Weiwei Zhang**; Kejia Zhuang	June 1st (14:00 -16:00, CET)
In high precision cutting, cutting edge microgeometry largely influences the machining performance and wear behavior of cutting tool. This study systematically analyses the effect of cutting edge microgeometry on surface roughness and white layer formation. A series of orthogonal cutting experiments of AISI 52100 steel is established with various edge preparations. Meanwhile, 2D finite element cutting model based on ABAQUS/EXPLICIT general software is developed to investigate the formation of white layer. In the proposed numerical model, the Johnson-Cook constitutive model is used to describe the elastic and plastic deformation of machined surface layer. Then, surface topography of machined workpiece is achieved to get 2D surface roughness. Besides, the phase transition mechanism with the consideration of the combination of stress and strain is used to predict the white layer. The investigation results show that enlarging chamfer width can improve surface roughness, while increasing chamfer angle has less effect on surface roughness. Moreover, both large rounded edge and large chamfered edge can contribute to white layer formation.			
PROCIR-D-19-01371R3	**Experimental study of the connection between process parameters, thermo-mechanical loads and surface integrity in machining Inconel 718**	**Thorsten Augspurger**; Markus Meurer; Hui Liu; Patrick Mattfeld; Thomas Bergs	June 1st (14:00 -16:00, CET)
The machining process has a major influence on the microstructure and the residual stresses of the manufactured surface and its final functionality. This functionality of surface integrity is of particular interest in safety critical aero engine parts made of temperature resistant super alloys such as nickel-chromium-based alloys. Besides the high tool wear, the machining of such materials is in particular challenging with regard to process induced microstructure alterations and the formation of low toughness and high hardness white layers. The current publication shows an experimental study and affiliated methodology in order to examine the influence of the process state conditions on the surface integrity, with regard to localized temperatures and forces causing white layer as well as residual stresses. On the experimental side a tailor made orthogonal milling setup was used in order to evaluate the transient temperature fields occurring in the workpiece together with the fluctuating process forces acting on its surface. This setup included a synchronized dynamometer, a thermal camera as well as a ratio pyrometer. The cutting forces and cutting normal forces under known engagement conditions were calculated from the transformed Cartesian dynamometer measurements and the measured cutter rotation angle. An evaluation of the surface integrity alteration was finally carried out analyzing the surface microstructure by light microscopy as well as residual stress measurements by X-ray diffraction.			
PROCIR-D-19-01381R2	**Initial investigation on Surface Integrity when Machining Inconel 718 with Conventional and Electrostatic Lubrication**	**Andrea De Bartolomeis**; Stephen T Newman; Alborz Shokrani	June 1st (14:00 -16:00, CET)
Inconel 718 is largely used in high-temperature applications where high hot strength and hardness are required, such as in aerospace and oil & gas industries. The majority of parts made from Inconel718, especially in the aerospace industries, are safety-critical components where surface quality is of significant importance. In industrial practice, the development of satisfactory surface integrity for high-performance applications of Inconel 718 is still a difficult process when machining parts with conventional cutting fluid. However, a potential alternative to conventional cooling is Minimum Quantity Lubrication (MQL), since it avoids large amounts of cutting fluid, and enhances the functional behaviour of machined components through superior surface quality. In addition, further improvements can be achieved with electrostatic lubrication (EL). With EL, the lubricant is electrosprayed increasing penetrability, atomization, deposition and			

wettability in the machining area. In this paper, a nozzle designed for electrostatic spraying using MQL is presented. The effects of EL on surface integrity are discussed in comparison with conventional MQL and Flood strategies. Machining experiments have been carried out in line with finishing conditions analogous to those adopted in industry for the milling of nickel-based super alloys. For these experiments, MQL and EL are supplied with the same setup, except for charging conditions. Surface integrity characteristics such as roughness, hardness and surface defects are investigated together with power consumption and tool life.

PROCIR-D-19-01384R3	**Graphene Nanoplatelets-Assisted Minimum Quantity Lubrication In Turning To Enhance Inconel 718 Surface Integrity**	**Rachele Bertolini**; Gong Le; Andrea Ghiotti; Stefania Bruschi	June 2nd (14:00 -16:00, CET)

Inconel 718 is regarded to be a difficult-to-cut nickel alloy due to its low thermal conductivity, high hardness, and chemical reactivity with tool materials at high temperature, which, overall, cause the generation of extremely high temperature at the cutting edge, contributing to deteriorate the surface quality of the machined workpiece. With the aim of improving the alloy machinability, the present paper evaluates the effect of Minimum Quantity Lubrication (MQL) on the turning performances of Inconel 718 compared to dry and flood lubrication conditions. In particular, for the first time, the feasibility of using graphene nanoplatelets as additives to a vegetable oil to form MQL mist is assessed. After having defined the optimal concentration of two graphene nanoplatelets of different size, the nanofluids were prepared and their stability as a function of time was assessed; afterwards, they were characterized by means of viscosity and specific heat capacity measurements as a function of temperature. The cutting performances were evaluated in terms of surface integrity and chip morphology. Results showed that the use of the nanofluid with the lowest graphene nanoplatelets size provided the best surface integrity compared to the ones obtained when using just MQL without any additive and standard lubricating conditions.

PROCIR-D-19-01385R2	**Influence of different cooling strategies during hard turning of AISI 52100 - part I: thermo-mechanical load, tool wear, surface topography and manufacturing accuracy**	**Stephan Basten**; Benjamin Kirsch; Werner Ankener; Marek Smaga; Tilmann Beck; Julian Uebel; Jörg Seewig; Jan C. Aurich	June 2nd (14:00 -16:00, CET)

This paper presents a characterization of the turning process for finishing of AISI 52100 in martensitic heat treatment state at various cooling conditions. With regard to the cooling conditions, LN2-cooling, CO2 snow cooling at varied mass flows, sub-zero metalworking fluids (MWF) at varied supply temperatures, and dry machining were examined. The tool temperatures, the process forces, the tool wear, the surface topography as well as the dimensional deviations of the workpiece caused by unintended alterations of the depth of cut due to a thermal expansion or contraction of the workpiece are analyzed. The application of MWF supplied at 20 °C results in an unchanging thermo-mechanical load in the tool-work interface and surface topography as well as in a high manufacturing accuracy. Dry machining leads to an increasing depth of cut of up to 10 %, resulting in radial dimensional errors. Cryogenic machining and using the sub-zero MWF supplied at -30 °C exhibit a different behavior due to high cooling effects: the depth of cut is reduced up to 10 %, also leading to radial dimensional errors. However, even though the depth of cut and thus the undeformed chip cross section is affected by up to 10 % depending the cooling condition, the mechanical load remains approximately constant during single cuts. In part II, the surface and near surface microstructure morphology of the workpieces is characterized.

PROCIR-D-19-01394R3	**Experimental identification of a surface integrity model for turning of AISI4140**	**Benedict Stampfer**; David Böttger; Daniel Gauder; Frederik Zanger; Benjamin Häfner; Benjamin Straß; Bernd Wolter; Gisela Lanza; Volker Schulze	June 2nd (14:00 -16:00, CET)
In this work an experimental study of the turning of AISI4140 is presented. The scope is the understanding of the workpiece microstructure and hardness-depth-profiles which result from different cutting conditions and thus thermomechanical surface loads. The regarded input parameters are the cutting velocity (vc = 100, 300 m/min), feed rate (f = 0.1, 0.3 mm), cutting depth (ap = 0.3, 1.2 mm) and the heat treatment of the workpiece (tempering temperatures 300, 450 and 600°C). The experimental data is interpreted in terms of machining mechanisms and material phenomena, e.g. the generation of white layers, which influence the surface hardness. Hereby the process forces are analyzed as well. The gained knowledge is the prerequisite of a workpiece focused process control.			
PROCIR-D-19-01396R2	**Complementary Machining: Effect of tool types on tool wear and surface integrity of AISI 4140**	**Jannik Schwalm**; Michael Gerstenmeyer; Frederik Zanger; Volker Schulze	June 2nd (14:00 -16:00, CET)
Complementary Machining is a process strategy for the time-efficient mechanical surface treatment of metallic workpieces. The characteristic of Complementary Machining is that after machining, a mechanical surface treatment is carried out using the cutting tool. The cutting tool moves over the workpiece surface in opposite direction to the machining process and induces an elastic-plastic deformation in the surface layer. Previous investigations have shown the possibility to achieve life-enhancing surface layer states in turning of AISI 4140 with Complementary Machining and to achieve fatigue strengths comparable to those after shot peening. In this paper, the influence of the tool types and process parameters, such as the feed rate, on the resulting topography and the tool wear, represented by changes of cutting edge microgeometry, during Complementary Machining of AISI 4140 are investigated based on the previous investigations. In addition to different substrates of the cutting insert, the focus of the investigations is also on the influence of tool coating. Both the tool wear and the resulting topography were analyzed tactilely and correlated with the process parameters. The results show a clear influence of the used substrate of the cutting insert and coating on the tool wear and the resulting topography.			
PROCIR-D-19-01399R3	**Milling parameter and tool wear dependent surface quality in micro-milling of brass**	**Stephan Dehen**; Eric Segebade; Michael Gerstenmeyer; Frederik Zanger; Volker Schulze	June 2nd (14:00 -16:00, CET)
Short life-time and high tool costs still remain major constraints for the micro-milling process. Understanding the wear mechanisms and their effects on the workpiece quality is essential for efficient tool usage. Usually, wear increases the cutting forces and reduces the emerging surface quality during the micro-milling process. Due to high tool costs, cutting parameters are usually chosen for optimal tool lifetime and/or process time rather than optimal surface quality. The scope of this paper is to investigate the correlation of the process parameters, strategy and wear status of the tool on the resulting surface topography. To reach this goal, micro-milling experiments were conducted, in which several grooves were milled using two end milling tools, new and worn, with a diameter of 1.5 mm and four cutting edges. The cutting speed and feed were varied, as well as the cutting direction. Brass was chosen as workpiece material to ensure a constant wear state of the tools during the experiments. During the cutting process the process forces were recorded and examined for their magnitude and frequency response. Furthermore, the grooves were analyzed optically for their surface roughness. The roughness shows in most cases slightly higher values for the specimen manufactured with the worn tool than the ones done with the new tool. The biggest influence on the surface roughness results from the feed rate, while cutting speed and milling strategy have a smaller influence. The measured cutting forces show similar tendencies, than the resulting surface			

roughness. The results show also a significant influence of tool wear on the vibration behavior during the process, while the influence of feed rate is mostly negligible. This results partly from the greater tool runout and bigger deviation of the cutting edges.

PROCIR-D-19-01407R2	**Evolution of the surface integrity while turning a fillet radius in a martensitic stainless steel 15-5PH**	**Maxime Dumas**; Frédéric Valiorgue; Guillaume Kermouche; Alexis Van Robaeys; Ugo Masciantonio; Alexandre Brosse; Habib Karaouni; Jöel Rech	June 2nd (14:00 -16:00, CET)

Surface integrity induced by longitudinal turning has been widely investigated in the literature. On the contrary, few works have aimed at investigating the surface integrity induced during turning of geometric singularities such as fillet radii. This paper investigates the surface integrity generated while turning a fillet radius in a martensitic stainless steel (15-5PH). The induced residual stresses, microstructure and mechanical properties have been characterized. Then, a geometrical analysis has revealed that the chip removal mechanisms vary continuously along the fillet radius, which, as a consequence, modify the cutting phenomena responsible of surface integrity modifications along the fillet radius. The study has highlighted that the microstructure remained stable but the residual stresses profiles differed especially regarding the compression peak intensity and the affected depth.

PROCIR-D-19-01408R2	**Impact of cutting tool wear on residual stresses induced during turning of a 15-5 PH stainless steel**	**Florent Clavier**; Frédéric Valiorgue; Cédric Courbon; Maxime Dumas; Joël Rech; Alexis Van Robaeys; Fabien Lefebvre; Alexandre Brosse; Habib Karaouni	June 2nd (14:00 -16:00, CET)

Finish turning is one of the key operations governing the residual stresses below the machined surface. The residual stress state depends on the cutting conditions and on the selected cutting tool system, i.e. macro geometry, cutting edge preparation as well as tool grade. However, tool wear often affects the interaction between the tool and the workpiece leading to severe modifications of the residual stress state. This work aims at investigating the influence of cutting tool wear on the surface integrity in longitudinal turning of a 15-5PH stainless steel. First, an experimental sensitivity study is performed to assess the effect of various wear modes on the residual stresses. Then a numerical model has been developed to understand the experimental observations and connect them to the thermomechanical loadings and local data within the near surface. The impact on residual stresses of three types of wear were tested (flank face wear, rake face wear and adhesion on the cutting edge) with the same cutting condition (Vc =120m/min, ap = 0.2 mm and f = 0.2 mm·rev-1). Based on the experiment, the numerical simulation proposes to observe the impact of wear on thermomechanical loadings by simulated a tool with a rounded cutting edge, a crater on the rake face and high flank face contact length. It follows that the impact of the rake face wear is extremely low, contrary to the rounded edge or the flank face wear which increased the contact length and significantly impact the loadings.

PROCIR-D-19-01409R3	**Effects on surface and peripheral zone during single lip deep hole drilling**	Robert Wegert; **Vinzenz Guski**; Siegfried Schmauder; Hans-Christian Möhring	June 2nd (14:00 -16:00, CET)

To adjust the defined surface and peripheral zone properties, such as hardness, residual stresses and surface quality, machining processes are in many cases followed by forming or heat treatment processes. A focused management of the machining process can already adjust the desired properties. The here presented

work is part of an interdisciplinary research project in the framework of the priority program "Surface Conditioning in Machining Processes" (SPP 2086) of the German Research Foundation (DFG). This research project has the main objectives to determine the thermo-mechanical as-is state of the drilling peripheral zone during the process by means of a sensor-integrated tool for single lip deep hole drilling as well as to control the process parameters to achieve the aimed peripheral zone properties. Preliminary test series are related to the determination of the thermo-mechanical boundary conditions. From the obtained results, the requirements concerning the sensor-integrated tool can be derived. Further steps include the development of a sensor-integrated tool for the in-process determination of temperature, forces, moments and vibrations, the selection and integration of sensor systems as well as the correlation of process factors with peripheral zone condition. Especially for the determination of the temperature at the affected zone, a multi-sensor approach was chosen. The formulation of a control strategy and its implementation in the deep hole drilling machine of the Institute for Machine Tools (IfW) will finalize the first project phase. Required surface and peripheral zone properties can then be controlled based on measurement and simulation data. Effects on the peripheral zone can then be investigated using process simulations. This contribution gives an overview of the objectives and the planned project steps. Experimental investigations on temperature, feed force and drilling torque during single lip deep hole drilling are described. Also first results of the process simulation and their validation with measured quantities are presented.

PROCIR-D-19-01421R2	**Influence of different cooling strategies during hard turning of AISI 52100– part II: characterization of the surface and near surface microstructure morphology**	**Werner Ankener**; Julian Uebel; Stephan Basten; Marek Smaga; Benjamin Kirsch; Jörg Seewig; Jan C. Aurich; Tilmann Beck	June 2nd (14:00 -16:00, CET)

This two-part paper addresses the impact of seven different cooling conditions on the finishing process as well as the resulting surface and near surface microstructure morphology of the rolling bearing steel AISI 52100 in martensitic heat treatment state. The applied cooling strategies are liquid nitrogen (LN2-) cooling, CO2-snow cooling at varied mass flows, sub-zero metalworking fluids (MWF) at varied supply temperatures, and dry machining. Part II of the paper concerns the changes in surface roughness, examined by an angle resolved scatter light sensor, micro hardness measurement, microstructure observations, residual stress and phase composition analyses in the near-surface area, caused by the turning process, that is characterized in Part I. The lowest cooling performance, i.e. dry machining, results in low compressive axial residual stresses and a high proportion of retained austenite at the near-surface area. High cooling performance strategies like CO2 cooling or sub-zero MWF show an opposite distribution of the mentioned parameters, wherein the coolants' lubrication effect is an important aspect. Microstructural differences resulting from the process parameters used in these investigations tend to be less significant. Thus, they do not allow reliable assignment of the microstructure to the cooling strategies used. However, different cooling conditions show an impact on residual stresses, phase distribution and surface topography of the workpieces to varying extents.

PROCIR-D-19-01429R2	**Adsorption and reaction layers when turning AISI 304 using various cooling strategies**	**Stephan Basten**; Benjamin Kirsch; Rolf Merz; Michael Kopnarski; Hans Hasse; Jan C. Aurich	June 2nd (14:00 -16:00, CET)

This paper deals with the surface chemistry of face-turned workpieces of AISI 304 using various cooling conditions. The workpieces were machined by means of LN2 cooling, CO2 snow cooling, conventional emulsion, sub-zero MWF as well as dry machining. With regard to the machining process, the tool temperature, the process forces, and the surface topography are investigated. The surface chemistry is studied using X-ray photoelectron spectroscopy (XPS). These investigations focus firstly on a detection of the elements occurring on the surface, their concentration and the dominant binding state of the main components. Especially the oxidation state of the surface due to the thermal load in the tool-work interface during machining is analyzed on the basis of O 1s and Fe 2p3 core

level photoelectron spectra. Secondly, sputter depth profiling using XPS is performed in order to qualitatively analyze the surface depth distribution of the detected elements. Adsorption and reaction layers can occur during turning of AISI 304 up to a depth of approximately 7 nm depending on the cooling conditions used. The use of emulsion, CO2 snow and dry machining results in a slightly higher carbon concentration. Regarding the oxidation in the reaction layer it can be concluded,that the higher the temperatures in the tool at distance of 1 mm to the contact zone during machining, the more oxidation occurs in these layers.

PROCIR-D-19-01432R3	**Investigation on residual stresses in milling of Ti-6Al-4V for both rake and flank application of different MWF strategies**	**Anshab kummamkandath**; Arnaud Duchosal; Antoine Morandeau; René Leroy	June 2nd (14:00 -16:00, CET)

This study investigates the effects of both rake and flank applications of different Metal Working Fluid (MWF) strategies on residual stresses in the machining of Ti-6Al-4V alloy. Cryogenic (Liquid CO2), Minimum Quantity Lubrication (MQL) and emulsion strategies were studied with modified CoroMill600 milling cutter via internal channels delivering media to insert rake face and flank face. The cutting force, minimum chip thickness and chip morphology were analyzed to understand more about this novel approach of rake and flank delivery of different MWFs in milling. The results reveal the formation of compressive residual stresses until 55-60µm beneath the machined surface irrespective of the type of MWF strategies. The highest value of compressive residual stress was observed at the machined surface of liquid CO2. The magnitude of the traced compressive residual stress profile shows a trend of positive slope gradient beneath the surface for both parallel and perpendicular to feed directional residual stress components. In contrast, residuals stresses in emulsion and MQL strategies were observed with a different trend in generation of compressive residual stress components, where the parallel to feed directional component shows an inflection point with a an initial negative slope gradient followed by a positive one to beneath the machined surface. An increase in the cutting forces and minimum chip thickness values were also observed for liquid CO2, due to the high shear resistance of Ti-6Al-4V alloy at machining zone, which was confirmed from the chip morphology analysis. Overall results show that cryogenic CO2 leads to higher compressive residual stresses at the surface and positive slope gradient beneath the material. The higher cutting forces in Z-axis and minimum chip thickness value in liquid CO2 are also attribute to the higher compressive stresses in Ti-6Al-4V workpiece at cryogenic CO2 environment.

PROCIR-D-19-01433R3	**Influence of built up edge on the surface topography of Ti-15Mo**	Denny Paris; Leonildo Pivotto; Carlos Eiji Hirata Ventura; **Armando Antonialli**	June 2nd (14:00 -16:00, CET)

Titanium alloys have been increasingly used in biomedical applications due to their mechanical and corrosion resistance, non-toxicity, and low modulus of elasticity. This latter property leads to intense material deformation during cutting and contributes to the formation of built up edge, which changes tool geometry and chip formation, altering workpiece surface quality. Its instability should also be taken into account, as it contributes to a high dispersion of roughness results. Considering the relevance of such effects in machining of a beta titanium alloy, this paper proposes a characterization of the built up edge formed during turning of Ti-15Mo and the correlation of its geometry with different surface roughness parameters. Obtained results show that the effective rake angle generated by the built up edge changes within a narrow range but its increase contributes to lower reduced peak height values obtained from the Abbott-Firestone curve.

PROCIR-D-19-01434R2	**The effect of cutting edge geometry, nose radius and feed on surface integrity in finish turning of Ti-6Al4V**	**Ian Brown**; Julius Schoop	June 3rd (14:00 -16:00, CET)

While the respective effects of nose radius, feed and cutting edge geometry on surface integrity have each been studied at depth, coupling between these effects is not yet sufficiently understood. Recent studies have clearly established that cutting edge micro-geometries may not only have positive effects on tool-life, but can also be used to tailor surface integrity characteristics, such as surface roughness and near-surface severe plastic deformation. To further a more fundamental understanding of the effects of cutting edge micro-geometries on surface integrity, experimental turning data was generated for a varied range of cutting tool geometries and feeds. Scanning laser interferometry was used in conjunction with a recently developed profile-analysis algorithm to analyze, characterize, and verify the geometry of complex cutting edge micro-geometries. Near surface nanostructure, and surface roughness of the produced surfaces were characterized and correlated to the varied tool geometries. An interaction between two geometry characteristics, predicted kinematic roughness and hone size, was discovered. Scanning laser interferometry analysis of the surfaces revealed that large hones provided either an increase or decrease in roughness, depending on predicted kinematic roughness.

PROCIR-D-19-01437R2	**Machining-induced surface integrity of holes drilled in lead-free brass alloy**	**Nima Zoghipour**; Emre Tascioglu; Gokhan Atay; Yusuf Kaynak	June 3rd (14:00 -16:00, CET)

This study presents the results of an experimental investigation on the effect of drilling process on surface integrity characteristics of lead-free brass alloy. Experimental data on dimensional accuracy and the surface quality of the holes, subsurface characteristics including microhardness and microstructure is presented and analyzed to evaluate surface integrity of machined specimens. This study demonstrates that cutting tools has strong influence on both microstructural aspects of lead-free alloy and resulting to hardening of the surface and subsurface along with deformation twinning.

PROCIR-D-19-01450R2	**Surface topography analysis of ball end milled tool steel surfaces**	**Francesco Giuseppe Biondani**; Giuliano Bissacco; Hans Nørgaard Hansen	June 3rd (14:00 -16:00, CET)

Many mechanical components require mirror–like surface appearance. When the application concerns the manufacturing of steel dies and moulds, material removal processes are the preferential choice in order to achieve the wanted dimensions and surface topography. In particular, ball milling is used in all those cases that require the machining of free form surfaces. When mirror-like surface appearance is in focus in such components, the final machining operations consists in a very shallow cut. The theoretical surface roughness (kinematic surface topography) that can be achieved in a finishing operation by ball end milling is orders of magnitude below the actual surface roughness. Beside runout and machine tool positioning errors, the quality of the cutting tools is a key factor in determining the surface topography. The combination of shallow depth of cut together with the finite size of the cutting edge radius of the tool are responsible for the occurrence of material smearing phenomena. Smearing, consisting in the accumulation of plastically deformed material over the surface, is particularly detrimental for the aesthetic functionality of machined components because it is responsible of the “foggy” appearance. In order to minimize the occurrence of the smeared material it is necessary to have a good understanding of the causes of the smearing formation process. The aim of this paper is the description and quantification of the smearing phenomena for ball end milling operations. The location of the smeared material is determined through SEM image analysis and related with the direction of the cutting speed and milling strategy. Subsequently the volume of the smeared material is quantified through a combination of confocal microscopy and SEM image analysis. Based on the volumetric analysis of the smeared material a new method for determining the Minimum Uncut Chip Thickness for the material is proposed.

PROCIR-D-19-01453R2	**Effect of progressive tool wear on the functional performance of micro milling process of injection molding tool**	Ali Davoudinejad; **Dongya Li**; Yang Zhang; Guido Tosello	June 3rd (14:00 -16:00, CET)
In micro milling process, tool wear is one of the significant research area and tool behavior during machining is rather unpredictable. As tool wear progress, the cutting edge geometry change and leading to lower performance and failure of the machined surface integrity. This work investigate the influence of the progressive tool wear during micro end milling of a functional surface (micro ridges) on the injection molding tool with H13 tool steel material. In order to monitor the tool wear progress, five different TiAlN coated carbides micro end mills with 500 µm diameter were used to carry out the experiments in different cutting distances 64 cm to 320 cm. The chip formation, burr formation and surface quality in different tool wear conditions were evaluated. The burr form and size were affected by cutting edge wear and dissimilar results obtained at the end of cut. Moreover, the analysis of chip geometry in microscopic scale allows evaluating the chip morphology and cutting mechanisms in different tool wear conditions. The machined slots by the profile analysis and the surface quality of parts decreased as the tool wear growth. This work contribute to improved knowledge of cutting mechanisms with worn tools causing dissimilar material removal and surface integrity during machining process.			
PROCIR-D-19-01456R2	**The influence of single-channel liquid CO_2 and MQL delivery on surface integrity in machining of Inconel 718**	**Luka Sterle**; Franci Pušavec; Dinesh Mallipeddi; Peter Krajnik	June 3rd (14:00 -16:00, CET)
Sustainable machining of difficult-to-cut materials requires effective cooling and lubrication techniques. To substitute conventional flood cooling and lubrication, different techniques such as cryogenic cooling and/or minimum quantity lubrication (MQL) can be used. Liquid carbon dioxide (LCO2) can be pre-mixed with different lubricants before its delivery to the cutting zone. This article investigates the influence of this recently developed cooling and lubrication method on surface integrity characteristics in milling of Inconel 718. Surface roughness, surface topography and microstructure were evaluated for flood lubrication, dry cutting and LCO2 machining using a single-channel LCO2 and MQL strategy. Moreover, two different lubricants were evaluated for MQL: (i) conventional MQL oil and (ii) solid lubricant molybdenum di-sulphide (MoS2). In addition to being environmentally friendly, MoS2 lubricated LCO2 showed comparable surface characteristics to flood lubrication. Also, the use of lubricated LCO2 resulted in higher part surface cleanliness compared to flood lubrication.			
PROCIR-D-19-01717R2	**Surface roughness response to drilling of Ti-5Al-5Mo-5V-3Cr using Ti-Al-N PVD coated and uncoated WC/Co tools**	**Alex David Graves**; Pete Crawforth; Susanne Norgren; Martin Jackson	June 3rd (14:00 -16:00, CET)
The surface response to drilling of the high performance titanium alloy Ti-5Al-5Mo-5V-3Cr (Ti-5553) with WC/Co tools cannot be assumed to similar to that of Ti-6Al-4V (Ti-64). Comparison of surface roughness for holes drilled in Ti-5553 with Ti-Al-N PVD coated and uncoated WC/Co tools at low and high cutting feed and speed was investigated. Cutting surface speed was shown to have more of an impact on surface roughness than that of feed, with high cutting speeds causing higher and more varied Ra value. In addition using coated tools at lower cutting speeds resulted in a lower average Ra. In most cases, the coated tolos achieved lower Ra values compared to the uncoated tools. This is thought to be due to a difference in cutting edge radius and better stability associated with the coated tools. High variance in RMax was observed for all tested conditions and tools, in some cases RMax was above 10 µm. Alicona and SEM imaging identified re-adhered material pickup as the probable cause. A correlation between torque and surface roughness was identified for the drilling of Ti-5553 and further investigation is proposed for using torque measurement as an alternate way of quantifying surface roughness without probe measurement or image analysis.			

PROCIR-D-20-00002R1	**Effect of tool coatings on surface grain refinement in orthogonal cutting of AISI 4140 steel**	**German Gonzalez**; Marcel Plogmeyer; Frederik Zanger; Saskia Biehl; Günter Bräuer; Volker Schulze	June 3rd (14:00 -16:00, CET)
Recrystallization mechanisms leading to the generation of ultrafine grains (UFG) by surface severe plastic deformation (S2PD) at low temperatures (< 0.5Tm (melting temperature)) have been investigated over the last years. Material removal processes like broaching impose large plastic strains along the shear plane during chip formation, leading in many cases to changes in the workpiece subsurface microstructure. In this work the influence of the cutting material on surface grain recrystallization were studied on broaching of AISI 4140q&t steel. Orthogonal cutting tests were carried out in dry conditions on a broaching machine using tools with different coatings. Uncoated cemented carbide inserts were geometrically prepared using fixed abrasive grinding processes and then coated by physical vapor deposition (PVD) with Al2O3 and CrVN thin films. Workpiece subsurface layers were analyzed after machining by Focused Ion Beam (FIB-SEM) and X-ray diffraction (XRD). The presented results show the influence of the cutting material on the final microstructure of the machined workpieces through the determination of the final grain sizes and dislocation densities.			

6.2 Topic 2: Surface integrity of parts machined with non-defined cutting edge

ID	Title	Authors	Q&A session
PROCIR-D-19-01353R3	**Surface integrity in micro-grinding of Ti6Al4V considering the specific micro-grinding energy**	**Mohammadali Kadivar**; Bahman Azarhoushang; Amir Daneshi; Peter Krajnik	June 1st (14:00 -16:00, CET)
Surface integrity is one of the most significant quality aspects of micro-grinding of difficult-to-cut materials. On the other hand, specific grinding energy is a fundamental parameter for describing the micro-grinding process. This paper addresses the surface integrity of the micro-ground surface of a titanium alloy under different cutting speeds and feed-rate-to-depth-of-cut (vw/ae) ratios at the same chip thickness. Three different cutting speeds and vw/ae ratios have been chosen and the residual stress of the workpiece, as well as the specific micro-grinding energy, have been investigated. The results showed that almost the same minimum specific grinding energy was obtained at tested cutting speed and vw/ae ratio. The results of the XRD analysis showed that contrary to the specific micro-grinding energy, the residual stresses of the ground surface changed by varying the cutting speed and vw/ae ratio. Higher cutting speeds resulted in lower compressive residual stress, and higher vw/ae ratios resulted in higher compressive stresses. This can be attributed to higher temperatures in the chip-formation process compared to the plastic deformation in micro-grinding at higher cutting speeds and lower vw/ae ratios which was proved via SEM micrographs.			
PROCIR-D-19-01392R2	**Residual stress change in multistage grinding**	**Ewald Kohls**; Robert Zmich; Carsten Heinzel; Daniel Meyer	June 1st (14:00 -16:00, CET)
Although high efforts were made to get a deeper understanding of grinding processes for many years, it is still not possible to clearly predict the alteration of the workpiece surface layer caused by grinding. To achieve this objective, the material loads occurring during grinding and the material modifications remaining in the material have to be considered. This knowledge enables the concept of Process Signatures describing correlations between internal material loads and			

induced modifications. For the prediction of residual stresses occurring in a single step grinding process, various theoretical approaches can be derived. In most of these approaches, grinding processes are investigated considering the same initial state of the workpieces in terms of material, heat treatment but also in terms of functional properties such as the residual stress state generated by the previous manufacturing processes. The influence of different initial states on the residual stress state after grinding is still not clear but of high interest, taking into account that grinding is usually performed as a process consisting of multiple steps (multistage grinding). In this context, this paper focusses on the effect of different initial states that are generated in the first grinding step on the grinding process in the subsequent grinding step e.g. regarding the residual stress state. Correlations are identified between internal material loads and the residual stress in multistage grinding. To gain a deeper knowledge of the interaction between thermally and mechanically induced internal loads, the combined laser and deep rolling process is introduced. In contrast to grinding, this process allows the variation of the thermal and mechanical load independently from each other, so that acting mechanisms regarding materials loads and resulting material modifications can be revealed which serve to optimize the multistage grinding processes in the future.

PROCIR-D-19-01416R3	**Investigation on Surface Integrity of Steel DIN 100Cr6 by Grinding Using CBN Tool**	**Mohammad Rabiey**; Pascal Maerchy	June 1st (14:00 -16:00, CET)

In many grinding processes and particularly in dry grinding, the residual stresses appears in form of tensile or compressive residual stresses. The knowledge of this resulting residual stress is very important for life cycle of the parts, because the residual stresses are directly superimposed with the operating stresses and loads. The grinding itself has a clear influence on the level of residual stresses in the component. With regard to the grinding process, grinding tools and material characterization, the amount and the type of the residual stresses are strongly dependent on the choice of grinding parameters. The thermal aspect of the grinding process (heat generation) tend to tensile residual stresses and mechanical aspects of the grinding process (material removal mechanism) reflect the compressive stress. In this work, the microstructure of work piece as well as residual stresses both in the feed direction of feed and perpendicular to the feed direction are investigated. The investigation shows that the residual stresses not only depends on the grinding parameter and material removal rate but also depends on topography of the wheel for instant by structuring. With proper structuring, it is possible to decrease the tensile residual stress or eliminate it even by dry grinding.

PROCIR-D-19-01422R2	**Development of surface residual stress and surface state of 42CrMo4 in multistage grinding**	Florian Borchers; Heiner Meyer; Carsten Heinzel; **Daniel Meyer**; Jérémy Epp	June 1st (14:00 -16:00, CET)t

In this study, cylindrical grinding of a 42CrMo4 (AISI 4140) steel with varied grinding sequence stages is analyzed regarding the effect of the different loads during multistage grinding up to the resulting final residual stress state and material structure. The grinding process was adjusted in a way to enhance the mechanical load with varying intensity and generate a pronounced compressive residual stress state in the final grinding step. Furthermore, consecutive multistage grinding processes were carried out and investigated. Using a mobile XRD system with a cos α method mounted on a robotic positioning arm, repetitive measurements of the ground surfaces were performed in the machine tool without simple removal, giving information about the surface residual stress development for each step of the process sequence. The information about the surface integrity development and possible effects of the grinding process during each step is relevant for the contact conditions and modification mechanisms which lead to the final surface integrity. It is shown that the final material state, normally accessible in post-process investigations, can also be achieved reliably by sequencing the process into several steps of a regular grinding process and depends strongly on the contact parameters in a non-linear way. It could be shown, that even the spark out step can lead to significant changes in the surface residual stress state.

PROCIR-D-19-01445R3	**Surface Integrity of Powder Metallurgy Superalloy FGH96 Affected by Grinding with Electroplated CBN Wheel**	Ziming Wang; **Xun Li**; Haining Wang; Jianhua Yu; Rufeng Xu	June 1st (14:00 -16:00, CET)

Powder metallurgy superalloy FGH96 is a key material for manufacturing aero-engine high temperature parts due to its excellent high-temperature mechanical performances. Machined surface integrity has a directly influence on the fatigue behavior. Unique properties of FGH96, like hightemperature strength and poor machinability, make it extremely difficult to control the machined surface integrity. Grinding technology utilizing super abrasive wheel is widely used in finish machining of powder metallurgy superalloy. Therefore, improving the fatigue property of parts by controlling grinding surface integrity is significantly important. Experimental results of grinding FGH96 with CBN electroplated wheel show that the grits size of wheel is the main factor influencing on surface roughness. With the decreases of the grits size, the surface roughness decreases gradually. Surface roughness of workpieces machined with 400#CBN wheel is Ra=0.76 μm, while that with 600#CBN wheel is Ra=0.56 μm. In the experimental conditions, feed speed and grinding depth have little influence on surface roughness. Grinding speed has hardly any influence on surface roughness. Meanwhile, the surface microhardness of workpieces is maintained at 460 HV to 500 HV and the surface residual stress is -700 MPa to -620 MPa. There is almost no plastic deformation in the microstructure of machined surface. Therefore, grits size of grinding wheel has a tremendous influence on surface integrity of powder metallurgy superalloy FGH96 in the range of experimental parameters, and controlling the surface roughness is a crucial method to improve the fatigue behavior of FGH96 parts.

PROCIR-D-19-01447R3	**Towards the prediction of surface roughness induced by the belt finishing process: influence of the material on the roughness reduction rate**	**Frédéric Cabanettes**; Oussama Cherguy; Cédric Courbon; Axel Giovenco; Sangil Han; Joël Rech	June 1st (14:00 -16:00, CET)

The belt finishing process is of great interest for the automotive industry so as to obtain smooth surfaces, especially after hard tuning operations. It enables to reduce and homogenize the surface roughness. It also prevents any shifting of surface quality from tool wear in hard turning. Belt finishing induces its own surface topography which will be rather independent of the previous one. Its surface signature is correlated to the abrasive belt topography. However models able to predict the final roughness of a part are missing. This article proposes to investigate the roughness reduction during the transitory state of the belt finishing process. The study is performed for different work materials. The main objective being to propose a first simple approach to predict the final roughness as a function of the initial roughness, work material and time.

6.3 Topic 3: Surface integrity produced by non-conventional processes

ID	Title	Authors	Q&A session
PROCIR-D-19-01334R2	**Fabrication of Interference Textures on Cemented Carbides Using Nanosecond and Femtosecond Laser Pulses**	**Shiqi Fang**; Daniel W. Müller; Christiane Rauch; Yanping Cao; Frank Mücklich; Luis Llanes; Dirk Bähre	June 2nd (14:00 -16:00, CET)
Laser surface texturing has become popular in recent years, as its application in various fields may result in relevant benefits in different fields, such as tribological performance enhancement of contact surfaces. As frontline engineering materials, cemented carbides are widely used in the mining and manufacturing industries. In the case of cutting tools, surface texturing of working surfaces of cemented carbides emerges then as an interesting option. In this work, line-like structures are produced on the surface of a chosen cemented carbide grade by the method of direct laser interference patterning (DLIP), using nanosecond and femtosecond laser pulses, respectively. Specific laser setups are individually configured to obtain topographic features on the scale of a micrometer. It is aimed to assess the production precision using such configuration and compare the possible ablation effects induced by the two typical laser setups. Topographic features of the produced patterns are characterized using confocal laser scanning microscopy. Morphological features and surface integrity are examined by scanning electron microscopy combined with focused ion beam (FIB) milling. It is found that satisfactory geometrical precision is achieved both nano- and femtosecond lasers. It also complies with theoretical estimations. Surfaces formed by the femtosecond laser are cleaner and show smoother patterns, exhibiting lower melting or microcrack formation.			
PROCIR-D-19-01340R2	**Impact of ultrasonic assisted cutting of steel on surface integrity**	Melanie Willert; **Tjarden Zielinski**; Kai Rickens; Oltmann Riemer; Bernhard Karpuschewski	June 2nd (14:00 -16:00, CET)
Diamond tools are typically used to fabricate optical molds. However, the excessive tool wear of diamond tools during machining steel still prevents their application for optical mold manufacturing. As steel molds potentially offer a higher lifetime than non-ferrous molds, the machining of steel to optical molds with diamond tools is desirable. This implies a great challenge for the production of tools for injection molded parts with complex geometry and high surface quality. As the most suitable method to prevent tool wear, ultrasonic assisted diamond cutting has been established. Since it is not yet known how the ultrasonic vibration during machining affects the surface integrity of manufactured components, an experimental study was carried out for this purpose. The conventional machining mode and the ultrasonic assisted elliptical vibration mode were compared. In addition to diamond tools, tools made of cubic boron nitride (CBN) were also included in the investigations to check whether ultrasonic assisted cutting with these significantly cheaper tools can achieve a similar supreme surface finish. For the evaluation of the Surface integrity, the surface topography was measured post-process with 3D white light interferometry and the generated subsurface zone was characterized by metallographic analysis of the processed samples. Additionally, the forces were measured in-process to determine the local mechanical load on the material. The results show that in ultrasonic assisted cutting, compared to conventional machining, an improvement in surface quality is achieved with diamond tools as well as CBN tools. In terms of plastic deformation, it was also found that the influence on the surface layer is significantly different compared to conventional cutting with both diamond tools and CBN tools. The differences are attributed to the ultrasonic impact. Regarding the process forces, an elliptical vibration lowers the process forces with a factor supposedly depending on the cutting edge radius and the material hardness.			

PROCIR-D-19-01346R3	**Surface integrity comparison of wire electric discharge machined Inconel 718 surfaces at different machining stabilities**	**Abhilash P. M.**; Chakradhar D	June 2nd (14:00 -16:00, CET)

Current study aims to investigate the effect of machining stability on the surface integrity of the wire electric discharge machined Inconel 718 superalloy. The wire electrode material used for machining is hard zinc coated brass. Experiments were conducted at various levels of machining stabilities, defined with respect to discharge energies and machining gap conditions. The topographical characteristics were analyzed by contact surface profilometer and non-contact 3D profilometer. Scanning electron microscope (SEM) images were analyzed to observe and compare the surface defects like microvoids, micro-cracks, micro globules, micro-craters on the samples machined at different stability levels. The least stable machining condition, with highest discharge energy, lowest inter electrode gap and least pulse off time, produced the most uneven topography. Recast layer (RCL) thickness was analyzed by observing the polished cross-sectional view of machined specimens under SEM. The conditions that provided the least RCL thickness were the most stable machining conditions. Furthermore, the surface layer characteristics like elemental contamination and thermal softening effects were analyzed using EDS and micro hardness tester respectively. All these characteristics have close relationship with the degree of machining stability.

PROCIR-D-19-01379R2	**Surface Microstructuring of Steel Components for CVD Diamond Coating by Ultrasonic Vibration Superimposed Face Milling using Tailored Tools**	**Richard Börner**; Maximilian Göltz; Thomas Helmreich; Andreas Schubert; Stefan Rosiwal	June 2nd (14:00 -16:00, CET)

Diamond coatings applied by chemical vapor deposition (CVD) provide extraordinary properties concerning hardness and wear resistance, which enables an increase of the performance or lifetime of highly stressed components. In particular, the combination of steel substrates and diamond coatings allows for numerous applications in several sectors of industry. However, there are significant challenges considering the coating adhesion strength. For example, the mismatch concerning the thermal expansion of steel and diamond commonly leads to a delamination of the coating. Thus, a suitable pre-treatment of the substrate surface is compulsory. With the aim of improving CVD diamond coating adhesion, ultrasonic vibration superimposed machining (UVSM) is applied when doing face milling on steel X46Cr13 specimens. The vibration direction is parallel to the tool axis and perpendicular to the feed direction. The tool wear and the surface microstructure are determined by 3D laser scanning microscopy. The investigations show, that predefined microstructuring of the substrate surface by UVSM contributes to an enhancement of the CVD diamond coating adhesion, especially regarding coatings with a thickness up to 10 µm. This can be referred to a better distribution or a reduction of thermally induced residual stresses in the diamond layer. However, a reliable generation of deterministic microstructures by UVSM significantly depends on the wear behavior of the tool. Uncoated cemented carbide grades exhibit considerable deficits reflecting in rapid tool wear. Therefore, adapted tool coatings are experimentally investigated, which result in an increase of the tool life and a reduction of the geometrical deviations of the microstructures. With an appropriate system of surface microstructure and coating, for example for tribological applications substantial improvements in terms of wear resistance and coefficient of friction are expected.

PROCIR-D-19-01380R3	**Laser finishing of polycrystalline diamond as strengthening mechanism**	**Manuela Pacella**	June 2nd (14:00 -16:00, CET)

Polycrystalline diamonds are widely used in the cutting tool industry for machining of aluminium alloy and metal matrix composites as they exhibit superior wear resistance. However, their wear characteristics are dependent on their microstructural features (i.e. percentage of binder phase and size of grains) which are defined during the sintering process. Low-energy fibre laser process of polycrystalline diamond composites with different grain dimensions is proposed to promote microstructural changes, enhance their hardness, and retain surface finish. Specimens were processed with a nanosecond pulsed fibre laser (ytterbium-doped)

at a wavelength of 1064 nm. Samples treated at various fluences, beam speeds and pulse durations were characterised via 3D interferometry, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDX) and microindentation hardness test. At a fluence below the composite's ablation threshold (i.e. 20 J cm2), the investigated finishing/polishing process for a coarse grain polycrystalline diamond resulted in a change of diamond grain size, a surface integrity of 140 nm and increased micro hardness (i.e. 240 GPa). The laser treatment caused plastic deformation of the grains, changing the intergranular boundaries area therefore impeding dislocation movements and enhancing hardness.

PROCIR-D-19-01390R2	**Influence of lubrication condition on the surface integrity induced during drag finishing**	**Irati Malkorra**; Ferdinando Salvatore; Joël Rech; Pedro José Arrazola; Joffrey Tardelli; Aude Mathis,	June 2nd (14:00 -16:00, CET)

Tribofinishing is one of the most popular polishing process in industry. The action of small abrasive media around parts enables to reduce significantly surface roughness and at the same time, to induce compressive residual stresses in the external surface layer. However, few scientific investigations have been made about this process. Whereas most of the previous works were focused on the effect of abrasive grains, the influence of lubrication and especially the filtering of the lubricant on the surface integrity have never been investigated before. This paper aims to study the influence of the presence of debris coming from the part and the media in the polishing process. For that purpose, rough surface parts (Ra~15 µm) have been tribofinished without and with lubrication filtering. Roughness parameters (Ra, RSm and Rsk), the offset between surface profiles and residual stresses have been compared. It is revealed that the lack of filtering leads to the presence of debris coming from the part and the media. This modifies tremendously the action of the media and prevent the surface from being polished properly. The reduction of roughness is saturated and the material is excessively deformed as a consequence of debris incrustations in the surface.

PROCIR-D-19-01415R2	**Surface Integrity Analysis of Ceramics Machined by Wire EDM Using Different Trim Cut Technologies**	Thomas Bergs; **Marcel Olivier**; Andrea Gommeringer; Frank Kern; Andreas Klink	June 2nd (14:00 -16:00, CET)

Electrically conductive ceramics are increasingly used in tooling and chemical industry, because of their high thermal and chemical resistance. The high hardness of the material is a major challenge for conventional manufacturing processes. Wire electrical discharge machining (WEDM) offers a good alternative, because the machining process is independent of the hardness. Nevertheless, the thermal material removal principle of WEDM leads to a microstructure change in the near-surface layer, which affects the load-bearing capacity of the material. In order to minimize these damages and to increase the load-bearing capacity, trim cuts must be used. Up to now, there are no processing technologies available on WEDM-machines for machining electrically conductive ceramics. Therefore, this study deals with the surface integrity improvement of zirconia/tungsten carbide (TZP-WC) as an electrically conductive ceramic by developing a material-specific technology with main and trim cuts. The surface improvement is verified by means of surface roughness measurements, cross-section analysis and bending strength tests. The dominant material removal mechanisms were identified to be melting, evaporation and spalling. This leads to smooth but glassy surfaces. The variation of the EDM characteristics caused a variation in the structure of the resulting surface. However, the discharge energy has a strong impact on both surface condition and removal mechanism. Bending strengths of over 900 MPa could be achieved by creating a smooth and nearly crack free rim zone. Trim cuts with higher electrical discharge energies cause fatal damage in the surface and lead to a breakdown of the bending strength.

PROCIR-D-19-01449R3	**Fabrication of mechanically enhanced superhydrophobic surface using nanosecond laser-based high-throughput surface nanostructuring (nHSN)**	Qinghua Wang; Avik Samanta; Amanuel Hailu; Scott K. Shaw; **Hongtao Ding**	June 2nd (14:00 -16:00, CET)

In this work, we conduct a systematic experimental investigation of surface integrity for steel and aluminum alloys processed via nanosecond laser-based high-throughput surface nanostructuring (nHSN) process. nHSN surface morphology and surface chemistry are first experimentally characterized, and the results show that surface nanostructure with proper surface chemistry is generated due to the combined effect of chemical etching and attachment of functional groups of low surface energy. Desired surface wetting behavior is achieved using a proper silane reagent during the nHSN chemical immersion treatment phase, while surface nanostructure can be finely modulated by adjusting the laser processing parameters. nHSN nanostructures with fluorosilane chemistry exhibit strong capability to repel water, leading to superhydrophobicity achieved on two important engineering metal alloys, namely steel and aluminium alloys. It is further experimentally demonstrated that the microhardness and anti-corrosion performance of the nHSN surface can be significantly enhanced compared with the untreated surface, indicating that the nHSN process is very effective for enhancing the mechanical strength and corrosion resistance of these important metal alloys. These results show that nHSN simultaneously creates random nanostructures, attains desirable surface chemistry and enhances surface integrity over large-area metal alloy surfaces.			
PROCIR-D-19-01451R3	**Experimental Study on Electrochemical Machining with Electrolyte Confined by Absorption Material**	**Wataru Natsu**; Junfeng He; Yu Iwanaga	June 2nd (14:00 -16:00, CET)
Electrochemical machining (ECM) is a promising approach to manufacture micro textures on the metallic workpiece surface. However, due to the fluidity of the electrolyte, the undercutting and stray corrosion always exist on the processing surface which make the surface shape and integrity difficult to control. This paper proposed a new surface texturing processing method called ECM with electrolyte confined by absorption material (ECM-ECAM). During machining, the non-metallic absorption material is inserted between the cathodic tool and the anodic workpiece after absorbing the electrolyte. Since the flowing electrolyte is replaced with the electrolyte that is absorbed and confined in the absorption material, limitation of the electrolyte existing area and the machining area is realized. In this way, micro textures could be generated with an effective voltage applied between the cathode and the workpiece. The machining principle, designed and fabricated machining system and the machining results are presented in this paper.			
PROCIR-D-19-01454R2	**Manufacturing of three-dimensional optical functional surfaces by diamond engraving of RSA 905**	**Dongya Li**; Yang Zhang; Xinquan Zhang; Dennis Neo; Ali Davoudinejad; Guido Tosello	June 2nd (14:00 -16:00, CET)
Functional surfaces have been investigated widely due to different applications in industries. In this paper, the surface functionality was the contrast generated by surfaces orthogonally textured with micro ridges. The principle to generate contrast was the anisotropic reflection led by the bevel surfaces of micro ridges. The surface quality of the micro bevels determined the reflection of the features. In the authors' previous work, such a functionality was successfully achieved on flat and cylinder surfaces of tool steel samples by micro milling. However, due to the limitation of micro milling process for microstructure fabrication, this study investigated the manufacturing of 3D functional surfaces of RSA 905 by diamond engraving. The 3D surface was shaped with hierarchical structures of micro bricks and micro ridges on the bricks: the surface was divided into micro grids then each grid was machined into a flat basic cell by using a round-tipped tool; the micro ridges were engraved on the basic cells with a sharp-tipped tool. In order to determine the feasibility of the microstructures to achieve contrast generation on 3D surfaces, a data matrix consisting of such micro ridges was patterned on a spherical concave and a freeform surface. The surface integrity was evaluated by measuring the surface roughness of the bevels on the micro ridges, characterizing the burr formation and detection of possible defects left on the micro features that affect the surface functionality. The successful scanning of the data matrix proved the microstructures successfully generated enough contrast to form readable codes. Furthermore, the contrast generated by the microstructures was quantified for process optimization by using a customized robotic measuring system.			

PROCIR-D-20-00001R1	**Experimental Investigation on Process Signature for EDM Processes**	Thomas Bergs; **Mehnoush Mohammadnejad**; Maximillian Witteler; Lukas Heidemmans; Andreas Klink	June 2nd (14:00 -16:00, CET)
In recent years, the term “process signature” has been introduced by different scientists. Within the framework of determining process signatures, the interaction between material loads resulting in material modifications should be investigated. During recently this idea is adopted to the EDM process. Therefore, as a further step towards this goal, in this work the interaction between the applied thermal loads (including temperature field as well as temporal temperature gradients) and the induced modifications in form of phase transitions and change in the grain size in the heat affected zone (HAZ) during single discharge experiments were analyzed. Due to the nature of the EDM process, namely its high frequency as well as high local and temporal gradients of the applied thermal loads, the in-situ measurement of the thermal loads is not always straightforward and accurate enough. Thereby, the determination of applied thermal loads has been done by using a heat transfer simulation model. Using the obtained results from the experiment and simulations, the microstructure modifications in the HAZ of an eroded workpiece are analyzed, with respect to the temperature gradients induced during a single discharge experiment.			

6.4 Topic 4: Surface integrity generated by mechanical surface treatments

ID	Title	Authors	Q&A session
PROCIR-D-19-01337R2	**Laser peening of 420 martensitic stainless steel using ultrashort laser pulses**	**Niroj Maharjan**; Zhenyuan Lin; Dennise Tanoko Ardi; Lingfei Ji; Mighui Hong	June 3rd (14:00 -16:00, CET)
Laser shock peening is an established method used to increase resistance of a surface to cracking and fatigue damage by inducing deep compressive residual stresses. Most of the current laser shock peening system utilizes a nanosecond pulse laser with very slow repetition rate(about 5-10 Hz), high pulse energy and a confining medium to constrain the plasma. On the other hand, ultrashort pulse lasers generally have a higher peak power density and operate at higher repetition rate than nanosecond pulse laser. Therefore, there is an opportunity to employ ultrashort pulse lasers to peen the surface in a fast and efficient way. However, limited studies have been performed to investigate the peening capability of ultrashort laser pulses. In this study, femtosecond (fs) pulse laser is used to peen a 420 martensitic steel surface under different coverage. The results show that fs laser can induce peening effect; however, peened depths are much smaller (around 20-30 µm) compared to high energy nanosecond pulse laser peening (up to 1 mm). A maximum compressive stresses of about -80 MPa was recorded at 981% coverage. Increase in coverage produced stress relaxation and did not increase the depth of influence. It was found that the state of the residual stresses depends on four main factors – intensity of ablation-induced shock wave, thermal effect of laser beam, phase transformation of the steel and surface mechanisms such as presence of nano-ripples and oxidation. Further experiments are ongoing to achieve higher magnitude of compressive residual stresses and higher depth of influence.			
PROCIR-D-19-01386R2	**Data Driven Optimization of Vibropeening**	Abhay Gopinath; **Wai Luen Chan**; A. Senthil Kumar	June 3rd (14:00 -16:00, CET)

Shot peening has been widely adopted as a fatigue life enhancement process, especially in the aerospace industry. High plastic deformation generated from high velocity shots impart a layer of compressive residual stresses up to sub-surface depth of about 100 microns. High surface waviness generated on the components' surface at the same time could lead to stress concentration and crack initiation, and hence an additional vibratory polishing step is needed as follow up process to reduce surface waviness caused by shot peening. This increase the process time and costs greatly despite the beneficial effect from fatigue life improvement. Vibropeening has been identified as an alternative surface treatment process which is able to induce comparable residual stress as shot peening, but with better surface finish as vibropolish in a single process. Recent studies showed that the concept of double vibratory process which incorporated an external vibration to the component on top of the vibration effect from machine, is able to reduce the process time even further to up to 50% to achieve desired outputs. In this paper, the author has investigated the effect of an additional external vibratory actuation at localized areas of the component in a vibropeening environment on Almen intensity, residual stresses and microstructure. The author also developed a smart vibropeening setup that is more suitable to the application in industrial production, enabling better process monitoring compared to conventional methods of RPM based control. The study showed that with vibratory actuation, an improvement in Almen intensity and residual stress was obtained, which could be potentially optimized further for uniform treatment of vibropeening with reduced process time.

PROCIR-D-19-01405R2	**Sequential multistage deep rolling under varied contact conditions**	**Matthias-Alexander Hettig**; Daniel Meyer	June 3rd (14:00 -16:00, CET)

It is possible to induce compressive residual stress, strain hardening and reduce the surface roughness by applying deep rolling to metallic surfaces. The resulting enhancement of surface integrity is based on the mechanical impact during the deep rolling process (internal material loads). For a single contact as well as multiple contacts with identical contact conditions, a good approximation for the correlation between the process parameters and the resulting material modification was achieved in previous works. By regarding the equivalent stresses, based on Hertzian equations, the modifications by means of the residual stresses were assessed. This paper shows an approach to describe the resulting material modification when using multiple contact stages in a deep rolling process under varied contact conditions. AISI 4140 is processed. For the generation of linear deep rolling tracks resulting from multistage deep rolling, the maximum internal material load is held constant also when varying the ball diameter between the different contacts. Three different levels of internal material loads are applied with two ball diameters and three different total numbers of contacts per linear track. The analysis of the material modifications is based on XRD measured residual stresses and geometrical track descriptions.

PROCIR-D-19-01463R2	**Robotic hammer peening-induced martensite in austenitic steels: Spatial distributions of plastic deformation and phase transformation**	**Hongfei Liu**; Chee Kiang Ivan Tan; Yuefan Wei; Guo Wei Lim; Wei Shin Cheng; Niroj Maharjan	June 3rd (14:00 -16:00, CET)

We studied the effect of robotic hammer peening (RHP) on plastic deformation, martensite transformation, and electrochemical process of austenitic stainless steels (SS304L) by employing microscopy and X-ray diffraction (XRD) characterizations. By changing the stepover distance dStep in a range of 0.1-2.0 mm we found that onset of surface plastic deformation at the center areas between adjacent grooves (i.e., those induced by RHP along the longitudinal feeding direction) occurs at dStep < 0.8 mm. XRD mapping along the transverse direction across the RHP-induced grooves revealed remarkable undulations in the distribution of martensite; the undulations decrease with the decrease in dStep and are eventually undetectable when dStep is reduced to smaller than 0.4 mm. These observations indicate that the martensite transformation occurs only at the peened areas, i.e., in the individual grooves rather than in their surrounding pileup materials. Morphological comparisons of the surface in the vicinity of the RHP-induced grooves before and after an electrochemical process were further carried

out. They revealed pitting corrosions of the surface and the pitting is significantly reduced by the RHP process, which is most likely due to the RHP-induced smoothening. These results shed light on cold-working, especially when designing RHP process, for advanced surface enhancements of stainless steels.			
PROCIR-D-20-00003R1	**Influence of subsurface properties on the application behavior of hybrid components**	Bernd Breidenstein; Berend Denkena; **Vannila Prasanthan**; Kolja Meyer	June 3rd (14:00 -16:00, CET)
In the manufacturing of massive components, demands such as weight reduction and increasing functional integration become more and more important. By combining different materials, for example high-strength steel and aluminium, hybrid massive components with specifically adapted properties for a required application behavior can be produced. The application behavior of hybrid components is especially influenced by its surface and subsurface properties, like e.g. residual stresses, surface roughness or material structure, which consequently determine the life span of such components. The previous machining process significantly influences these properties. The modifications of the above-mentioned subsurface properties (residual stresses and material structure) in the joining zone of hybrid components during deep rolling and longitudinal turning are analysed. In order to examine the influence of these properties on the life span of hybrid components, rotating bending tests and in situ scanning electron microscope (SEM) investigations during tensile tests are conducted. The investigations show that subsurface properties in the joining zone have a deep impact on the application behavior of hybrid components.			

6.5 Topic 5: Finishing and surface integrity of parts produced by additive manufacturing

ID	Title	Authors	Q&A session
PROCIR-D-19-01373R2	**Surface and sub-surface integrity of Ti-6Al-4V components produced by selective electron beam melting with post-build finish machining**	**Thomas Childerhouse**; Everth Hernandez-Nava; Rachid M'Saoubi; Nikolaos Tapoglou; Martin Jackson	June 4th (14:00 -16:00, CET)
The emergence of metal additive manufacturing (AM) processes offer manufacturers a promising alternative to traditional forging and casting techniques for the production of near net shape titanium alloy components. However, limitations in both the surface finish quality and the geometric accuracy of parts produced by AM means that post-build finish machining of the part remains to be a requirement to produce high precision components. Furthermore, the fatigue performance of material produced directly by these processes is often limited by both the por surface finish and porosity related defects which occur within the material. This study investigates the implications of machining stock allowance on the surface integrity of Ti-6Al-4V specimens produced by selective electron beam melting (SEBM) followed by post-build finish machining. The study revealed that the exposure of porosity related defects on the newly machined surface varied depending on the depth of material removed from the as-built specimen surface during machining. Four point bend fatigue testing of the specimens was carried out to determine the effect of the exposed surface defects on the fatigue performance of the material. This study highlights that the non-uniform distribution of pores within SEBM Ti-6Al-4V means that careful considerations must be given regarding machining stock allowance in the design of these components due to the implications of material removal depth on surface integrity.			

PROCIR-D-19-01388R2	**Surface integrity in abrasive flow machining (AFM) of internal channels created by selective laser melting (SLM) in different building directions**	**Sangil Han**; Ferdinando Salvatore; Joël Rech; Julien Bajolet; Joel Courbon	June 4th (14:00 -16:00, CET)

Selective laser melting (SLM) can produce a conformal cooling channel that is widely used in the mold industry. However, SLM inherent rough surface can cause stress concentration, reducing the fatigue life of the mold. In addition to the surface roughness, residual stress can affect fatigue life. Therefore, it is necessary to improve surface integrity, such as surface roughness and residual stress, of the internal channels created by SLM. The internal channels (ø3 mm) are created by SLM in horizontal and vertical directions. As a counterpart of the SLM process, the internal channel (ø3 mm) is also made by the conventional process, such as electrical discharge machining (EDM) in a wrought bar. After internal channels are finished by abrasive flow machining (AFM), the evolution of the internal channel's surface integrity, such as surface roughness and residual stress, is investigated. The surface roughness of the horizontally and vertically SLM built as well as EDM generated channels are measured with a stylus. The initial surface topography of the SLM built channels differs significantly depending on the SLM building direction. The stylus measurement reveals significant improvement (< 1 µm Ra) in surface roughness of all internal channels after AFM. The residual stress on the internal surface channel is measured with X-ray diffraction (XRD). After AFM finish, the compressive residual stress in the AFM flow direction is found to be induced on the SLM built and EDM generated channels. Thus, AFM finish can be considered to be beneficial to the surface integrity of the internal channel created by SLM and EDM.

PROCIR-D-19-01393R2	**Wire electrical discharge polishing of additive manufactured metallic components**	Jibin Boban; **Afzaal Ahmed**; M Azizur Rahman; Mustafizur Rahman	June 4th (14:00 -16:00, CET)

Additive manufacturing (AM) is a rapidly developing technology in biomedical, aerospace and automobile industries. However, adoption of this technology on a larger production scale remains limited. This is primarily due to the drawbacks of present AM processes associated with achievable dimensional accuracy and surface integrity of the fabricated component. The average surface roughness (Ra) of the component ranges from 3 µm to 10 µm with stair-stepping effects, balling on surfaces resulting in poor dimensional accuracy. Therefore, post-processing methods like abrasive flow finishing, laser polishing, chemical polishing and traditional finish machining is often used to meet the desired surface integrity and accuracy. However, some of these post-processing methods are quite expensive leading to overall increase in the production cost of the component. On the other hand, methods like etching and sand blasting are time consuming and not suitable for component with intricate geometries. In this paper, low energy wire electrical discharge polishing (WEDP) has been employed to achieve the desired surface integrity and finish. Initially, experiments were conducted to analyse the finishing achieved on planer additive manufactured stainless steel (SS316L) specimens. A significant reduction in roughness of maximum 80 % was obtained at various settings for pulse on time and servo voltage. In addition, SEM and EDS analysis were also carried out to study the microstructure and composition after WEDP. From the study, it was found that the WEDP process is a promising method to finish metallic AMed components.

PROCIR-D-19-01418R2	**Surface Integrity of Machined Electron Beam Melted Ti6Al4V Alloy Manufactured with Different Contour Settings and Heat Treatment**	**Dinesh Mallipeddi**; Lars-Erik Rännar; Sinuhe Hernandez; Emil Strandh; Peter Krajnik; Tina Hajali; Lars Nyborg; Alex Bergstrom	June 4th (14:00 -16:00, CET)

The powder-bed-fusion-based Electron Beam Melting (EBM) is rapidly gaining interest as a feasible process in the manufacturing industry for producing intricate Ti6Al4V components. However, there is still a challenge of reducing production time and optimizing surface roughness. One way to improve surface roughness is to optimize the melting strategy, i.e. contour setting. This not only influences the obtained surface topographical features, but also the production time. Most

industrial applications require subtractive post processing (machining) to obtain a desired functional surface. This paper is concerned with analysing surface and subsurface in turning of Ti6Al4V alloy, manufactured by EBM using different contour settings. Also, the effect of subsequent heat treatment, i.e. Hot Isostatic Pressing (HIP) is studied. The results indicate that avoiding of contours require a machining allowance of 1 mm to obtain surface roughness of about 0.5 µm (Sa). In case of three and five contours the machining allowance can be reduced to 0.25 mm. Microstructural differences originating from the subsequent HIP operation show no effect on machinability. Tensile residual stresses are generated when reaching down to the heat effected zone of contour settings.

PROCIR-D-19-01420R3	**Selection of machining condition on surface integrity of additive and conventional Inconel 718**	**Sasidharan Periane**; Arnaud Duchosal; Sébastien Vaudreuil; Hicham Chibane; Anthony Xavior; Antoine Morandeau; René Leroy	June 4th (14:00 -16:00, CET)

Inconel 718 is a nickel-based superalloy used in steam turbines, jet engines, etc., where it is subjected to high thermomechanical loads. Inconel 718 is the most preferred alloy in the above applications due to its excellent resistance to fatigue and creep. Inconel 718 is mainly strengthened by the precipitates which were formed during the heat treatment process by the combination of elements like Nb, Ti, and Al along with the base element Ni. Selective Laser Melting (SLM) is one of the most used additive manufacturing processes to manufacture components with high dimensional accuracy in a flexible manner with less material usage. The samples fabricated by SLM were subjected to two heat treatments: Hot Isostatic Pressing (HIP) to improve the density followed by the Aeronautic Heat Treatment (AHT) in order to improve the material properties. The heat-treated SLM samples have the same mechanical properties of the conventional Inconel 718 fabricated by the Cast and Wrought (C&W). The Central Composite face-centered Design (CCD) was used for the Design of Experiments (DOE) in which three different cutting speeds (vc) and feed rates (fz) were considered whereas the depth of cut (ap) is kept constant. Machining experiments were conducted under dry, Minimum Quantity Lubrication (MQL) and emulsion (Wet) conditions on both the cast and wrought (C&W) Inconel 718 and additive fabricated SLM Inconel 718. The optimum cutting condition for C&W and SLM Inconel 718 samples was determined based on three criteria: minimum specific cutting energy (Wc), minimum tool wear (Vb) and minimum surface roughness (Ra). From the overall results, it is being inferred that the SLM Inconel 718 produced better results compared to C&W Inconel 718.

PROCIR-D-19-01426R2	**On the surface integrity of additive manufactured and post-processed AlSi10Mg parts**	**Debajyoti Bhaduri**; Pavel Penchev; Stefan Dimov; Khamis Essa; Luke N Carter; Catalin I Pruncu; Jun Jiang; Daniele Pullini	June 4th (14:00 -16:00, CET)

The research centres on the evaluation of surface integrity of AlSi10Mg parts produced via laser-based powder bed fusion (LPBF) process, followed by vibratory surface finishing. The alloy is chosen for its applications in lightweight components used in electronic packaging, automotive and aerospace sectors. Initial experiments involve optimisation of key LPBF process parameters by analysing the surface roughness and density data of the built parts. A Taguchi L18 orthogonal array is used for the optmisation trials with variations in the laser power (P), beam scanning speed (v), hatch spacing (H) and island size (I). Latter experimental phase deals with microhardness and microstructure assessment of heat treated LPBF specimens that are produced using the optimised LPBF parameters, i.e. P: 250 W, v: 1500 mm/s, H: 75 µm and I: 2 mm. Microhardnesses of the annealed samples reduce by ~12% with respect to the as-built parts and the values remain almost unchanged from the annealed state following solution treatment and ageing. The fish-scale like melt-pools observed on the unheat treated samples begin to fade off in the annealed specimens and completely disappear after solution treatment and ageing, with silicon particles dispersed all over the aluminium matrix. The final experimental phase involves vibratory surface finishing of the as-built LPBF parts using a vibrating ceramic media mixed

with different acid and amine based liquid compounds for 1-6 hours, followed by vibrating in a maize based media for another 1-6 hours. The process aids in reducing the parts' roughness, Sa by ~35-70%, however the effect is more prominent when using the ceramic media.

PROCIR-D-19-01428R2	**Analysis of the surface integrity induced by face milling of Laser Metal Deposited Ti-6Al-4V**	**Achref Kallel**; Arnaud Duchosal; Hedi Hamdi; Guillaume Altmeyer; Antoine Morandeau; Stephane Meo	June 4th (14:00 -16:00, CET)

The Laser Metal Deposition (LMD) is an additive manufacturing process which is gaining good competence in manufacturing and repairing complex functional parts. However, the produced parts require conventional machining operations in order to enhance the surface quality and the material properties. Due to the highly localized heat input experienced by the sample during the building process, significant variation of the local material properties can appear within the produced components. This could affect the machinability of the parts produced by the LMD process. This study aims to investigate the milling process and its effect on the resulted surface integrity of Ti-6Al-4V components produced by the LMD process. The heat treatment was performed in order to homogenize the microstructure of the material. The conventional Ti-6Al-4V was taken as a reference material sample. Depending on the cutting process parameters, the cutting forces and the surface roughness of the machined LMD parts were 10-40% and 18-65% respectively higher than the conventional samples. The compressive residual stress in the machined LMD samples were 11-30 % higher than the conventional specimen. These differences are related to microstructure and grain size differences between the tested parts.

PROCIR-D-19-01440R2	**Surface integrity induced in machining additively fabricated nickel alloy Inconel 625**	Lihang Yang, Kaushalendra Patel, Krzysztof Jarosz, **Tugrul Özel**	June 4th (14:00 -16:00, CET)

Parts fabricated with metal additive manufacturing processes such as laser powder bed fusion (LPBF) or laser metal deposition have much different microstructure than cast or wrought counter parts. Machining processes employed on these parts to finish them to their final net shape and surface quality add further complexity to the subject. The machined surface morphology has an important effect on the service performance of components, including fatigue life, wear resistance and corrosion resistance, and is closely related to machining conditions. It is essential to investigate the effect of machining on the surface morphology of additively fabricated workpieces. This paper investigates surface topography and surface integrity of machined nickel alloy Inconel 625 test workpieces that were built using LPBF with two different scan strategy orientations. The results indicate that the surface topography and integrity is affected by relative orientation of cutting direction to the build direction and scan strategy orientation. Finished surfaces indicative of surface defects such as feed marks, material side flow, adhered materials, and smeared materials were also investigated. It is evident that surface integrity can be significantly improved by an optimized milling process.

PROCIR-D-19-01455R3	**Drilling process and resulting surface properties of Inconel 718 alloy fabricated by Selective Laser Melting Additive Manufacturing**	**Yusuf Karabulut**; Yusuf Kaynak	June 4th (14:00 -16:00, CET)

One of the challenges is to produce holes with expected dimensional accuracy in metal additive manufacturing. Although post-processing is usually carried out for the additively manufactured components but improving the quality of the holes produced through additive manufacturing seems to be requirement. Otherwise, it is difficult to obtain expected quality for the holes in metal components. Therefore, this study focuses on drilling operation of Inconel 718 alloy fabricated by selective laser melting additive manufacturing. Specimens fabricated by selective laser melting (SLM) were drilled using carbide drill bit under various drilling

conditions including cutting speed and feed values. The measured outputs were surface quality of drilled hole, surface topography, surface and subsurface microhardness, and microstructure. Obtained results were compared with the results from wrought Inconel 718. This study showed that drilling process helps to improve the surface quality of additively manufactured Inconel 718 by reducing the surface roughness. Besides, increased feed rate results in work hardening effect on the hole Surface and eventually microhardness of surface and subsurface increases notably.

6.6 Topic 6: Surface integrity of composite materials

ID	Title	Authors	Q&A session
PROCIR-D-19-01411R2	**Multilayer structure dependent performance behaviour of CVD diamond thin film drilling tools during CFRP machining**	Eckart Uhlmann; **Daniel Hinzmann**; Walter Reimers; Katrin Böttcher	June 4th (14:00 -16:00, CET)
The potential of chemical vapour deposition (CVD) diamond coated tools in its application for machining lightweight materials, such as carbon fibre reinforced plastics (CFRPs), is currently limited to coating adhesion failure. Resulting spontaneous delamination and subsequent critical tool wear adversely affect the reproducibility of tool lifetime, process stability as well as machining quality. Although different morphologies and its variation of layer thicknesses on geometrically complex tools can be deposited, the interaction of coating and substrate determines the overall cutting tool strength. In addition, influencing factors on coating adhesion generated by the manufacturing process, such as tool substrate production and coating parameters, cause a high variance with regard to the cutting tool performance even within one tool batch. The scope of the presented investigation includes the application of varying CVD coated drilling tool specifications in order to analyse its performance regarding wear and process behaviour during machining of CFRP. Tool substrates ranging from tungsten carbide (WC) with varying cobalt content to silicon nitride (Si3N4) and silicon-aluminiumoxide nitride (SiALON) individually offer substrate material related tool failure conditions. Although Si3N4 substrates show an increase in averaged machined boreholes compared to WC-based substrate materials by 52 %, occasional tool shank breakage indicates a lack of mechanical strength within this tool specification. In contrast, WC-based substrate materials show typical wear on the rake face until reaching the wear criterion. Thus, process reliability is limited either by spontaneous coating delamination regarding WC-based cutting tools or cutting tool shank failure concerning silicon-based substrates respectively. The resulting workpiece integrity, i. e. surface quality, suffers from coating delamination during machining whereby fibre protrusion as well as workpiece delamination is occasionally observable.			
PROCIR-D-19-01424R2	**Study of the machining induced damage in UD-CFRP laminates with various fibre orientations: FE assessment**	**Fernando Cepero-Mejías**; Kevin Kerrigan; Jose Curiel-Sosa; Vaibhav Phadnis	June 4th (14:00 -16:00, CET)
Finite elements (FE) provide an excellent and low-cost approach in the assessment of composite machining induced damage. This article is focused on the evaluation of the damage underlying the machined surface through the development of a novel 3D FE model in composite machining. Sub-surface damage of UD-CFRP with fibre orientations from 0º to 90º is evaluated. An algorithm to assess composite damage evolution and chip formation is inserted via user-defined subroutine. Damage initiation is determined using Hashin's failure criteria for fibre damage modes, while matrix damage modes are assessed via Puck's failure criteria. Subsequent damage evolution is modelled using an energy based linear damage degradation law. Numerical results reveal relevant advances in the prediction of the damage induced underlying the machined surface for fibre orientations from 60º to 90º obtained in previous investigations.			

6.7 Topic 7: Methods to characterise and control surface integrity properties

ID	Title	Authors	Q&A session
PROCIR-D-19-01326R2	**Surface drag analysis after Ti-6Al-4V orthogonal cutting using grid distortion**	**Andres Sela**; Gorka Ortiz-de-Zarate; Daniel Soler; Patxi Aristimuño; Guénaël Germain; Pedro José Arrazola; François Ducobu	June 4th (14:00 -16:00, CET)
Surface integrity directly affects the mechanical behavior of the workpiece, which is especially relevant on fatigue behavior. To characterize the quality of the machined surface, aspects such as material damage, roughness or residual stress are considered. Measurement of the material damage of the surface is characterized in some cases as surface drag, depth of the affected machining zone, a phenomenon which takes place due to plastic strain in the surface layer caused by machining stress which could have an influence on residual stress. Surface drag measurement done with optical microscopes has relevant uncertainty. In this paper, a methodology to measure the surface drag with lower uncertainty is proposed. The method consists of measuring the deformation of a grid as a result of the machining process. The grid was created with micromilling. The method was applied to analyze the effect of feed on the surface integrity after orthogonal cutting of Ti-6Al-4V. The depth of the affected layer was measured using a 3D optical measuring device (Alicona Infinite Focus IFG4) and compared with numerical simulations and a good agreement was achieved. In comparison with optical microscope results, it can be concluded that traditional method underestimates surface drag.			
PROCIR-D-19-01350R2	**Ductile-brittle transition detection in scratching of single crystal silicon using charged particle emissions**	**Arun Veerabagu Sankara Subramanian**; Chirag Alreja; Sathyan Subbiah	June 4th (14:00 -16:00, CET)
During machining of single-crystal silicon, material removal involves two modes ductile shear-based removal and brittle fracture-based removal. Ductile shear-based chip removal occurs when fracture is suppressed due to local stress conditions along with reduced chances of defect involvement and is desirable for achieving better surface integrity of the machined silicon wafer. In this work, we use charged particle emissions to identify mode of material removal (ductile or brittle) during scratching of a silicon wafer. Scratching tests were performed using a pin-on-disc tribometer setup with a conical diamond tip indenter, in which the wafer was held at an inclined position to achieve a varying-depth tapered scratch. The varying-depth scratch test was performed in such a manner that both ductile-to-brittle and brittle-to-ductile modes occur in a single scratch test. The charged particles emitted during the material deformation were collected using a Faraday plate mounted in the vicinity of the indenter and the intensity of the charged particles were measured using a sensitive femto/picoammeter. The scratch depth was measured using a 3D surface profiler and the mode of fracture was identified by examining crack density per unit length in a scanning electron microscope. These results were then correlated with the emission intensity signals. From the experimental results, a positive current intensity was observed for ductile mode of scratching and highly varying current intensity signal is observed during brittle mode of scratching. The results obtained were consistent over time and exhibited good repeatability. The present work indicates suitability of employing charge emission signals to detect mode of material removal during scratching of silicon. This work can be field-tested by conducting diamond turning experiments of silicon in real-time machining environment further testing the scope of use of charged particle emission to monitor real-time machining process.			

PROCIR-D-19-01357R3	**3D FIB/FESEM tomography of grinding-induced damage in WC-Co cemented carbides**	Jing Yang; Joan J Roa; Magnus Odén; Mats Johansson-Jõesaar; **Luis Llanes**	June 4th (14:00 -16:00, CET)

WC-Co cemented carbides (hardmetals) represent the backbone materials for the tooling industry. In order to achieve particular tool geometries, diamond wheel grinding is a well-established method for machining hardmetals. Grinding-induced damage has been proven to strongly affect the performance and reliability of the machined tools. Assessment of grinding-mechanisms and induced surface integrity changes has usually been limited to monolithic ceramics, and it is particularly done on the basis of post-failure fractographic examination. In this work, characterization of grinding-induced damage of a WC-Co grade has been conducted by means of focused ion beam (FIB) tomography. The study includes a 3D description of the damage scenario, based on a reconstruction from successive parallel slices. Our results show that grinding induces a 200-400 nm thick surface layer containing fragmented WC grains and smeared Co phase morphology. A highly anisotropic subsurface microcrack network is generated. The discerned microcracks follow different microstructural paths: running through the binder, close to WC/Co interfaces or transgranular within the carbide phase. Very interesting, completely or near- lateral cracks (parallel to the ground surface) are found to be the predominant damage feature, whereas only few completely or near- orthogonal (perpendicular to the ground surface) cracks are discerned. Results are discussed in terms of material removal mechanisms during grinding of cemented carbides and surface integrity effects on the mechanical performance of hardmetal tools under service conditions.

PROCIR-D-19-01362R3	**Experimental approach for a grinding burn in-process inspection system based on Eddy Current**	**Jose Luis Lanzagorta**; Lander Urgoiti; David Barrenetxea; Paula Ruiz Vázquez; Jose Alberto Sánchez	June 4th (14:00 -16:00, CET)

During grinding some detrimental microestructural changes can appear in the workpiece if the temperature reaches the tempering point in the contact zone. This “thermal damage”, commonly known as grinding burn, has negative consequences in the workpiece mechanical properties and its avoidance and detection is crucial to optimize grinding operations. Magnetic methods (Barkhausen noise, Eddy Current) are nowadays applied post process to detect burns automatically and without the subjectivity of the inspector (Acid Etching Method). However, the potential use of these magnetic methods during in-process inspection is a matter that has not been studied in detail yet. The objective of this paper is to evaluate the Eddy Current technology for the grinding burn inspection in combination with other process outputs. Experimental tests have been performed in the machine at different conditions considering different inspection strategies. The results show the benefits of the present approach and serve as a starting point for the development of a future in-process inspection system.

PROCIR-D-19-01366R3	**Sensorization of Shot Peening for Process Monitoring: Media Flow Rate Control for Surface Quality**	**Augustine Teo**; Yicheng Jin; Kunal Ahluwalia; Ampara Aramcharoen	June 4th (14:00 -16:00, CET)

Shot peening is a surface enhancement process that is extensively used by various industries to impart compressive residual stresses to enhance the fatigue life of the component. Almen strip system is currently used to quantify the process quality - however this method is not real-time and a common bottleneck in production due to long times associated with developing saturation curves using Almen strip. With the main objective of real time process monitoring for shot peening, Acoustic Emission (AE) sensor and accelerometer were implemented at the nozzle and experimental trials were conducted at different operating conditions. The behavior of AE sensor and accelerometer with respect to input parameters for different types of media was reported. It was concluded through this study that AE sensor and accelerometer signal when implemented on the nozzle shows initial potential. Future work includes several improvements to increase the data accuracy and reduce uncertainty; thereafter, the sensors could be used as an indirect means to monitor downstream media flow rate of the media, which affects intensity and subsequently induced compressive residual stress on the component.

PROCIR-D-19-01368R3	**Surface integrity of additive manufacturing parts: a comparison between optical topography measuring techniques**	**Wilson Tato**; Liam Blunt; Iñigo Llavori; Andrea Aginagalde; Andrew Townsend; Alaitz Zabala	June 4th (14:00 -16:00, CET)

Additive Manufacturing (AM) presents significant industry-specific advantages allowing the creation of complex geometries and internal features that cannot be produced using conventional manufacturing processes. However, a current limitation of AM is the degraded dimensional control and surface integrity of specific surfaces. The parts are constructed through layer-by-layer approach, each layer presenting a characteristic 'fingerprint'. The functional performance of the final part is influenced by the morphology of the outer surface as well as by the surface quality introduced at intermediate layers. Surface texture metrology therefore can play an enabling role in AM-related manufacture and research. The use of optical topography measurement instrumentation allows for a high level of detail in the acquisition of topographic information. Some of the most commonly used optical measuring instruments are Vertical Scanning Interferometry (CSI), Imaging Confocal Microscopy (CONF), and Focus Variation (FV), each one has benefits and drawbacks in terms of acquisition time and measurement resolution. AM surfaces overall present complex topographical features, requiring the acquisition of large surface areas and large z-scans which considerably increases the acquisition time. Speed is a key factor in industrial practice, and time optimization is required for quality control and surface analysis before down-stream processes. This paper reports on the measurement and characterisation of the surface texture of metal powder bed fusion AM parts. All measurements were performed in the same SENSOFAR S-NEOX instrument using the commonly used optical technologies (CSI, CONF, and FV) and the latest step in confocal measurement technology called Continuous Confocal (C-CONF). The resolution and acquisition time of each technique is analysed in order to check the suitability of each method to characterize and describe the AM surface microstructures in a time-efficient way.

PROCIR-D-19-01372R2	**In-process workpiece displacement measurements under the rough environments of manufacturing technology**	**Andreas Tausendfreund**; Dirk Stöbener; Andreas Fischer	June 4th (14:00 -16:00, CET)

The goal-oriented manipulation of surface integrity by certain manufacturing processes requires comprehensive knowledge of the physical stresses induced into the workpiece. Properties such as the hardness are strongly influenced by mechanical stresses, induced during machining. The basic prerequisite for a comprehensive comparison of different manufacturing processes is the ability to precisely determine the stresses in the form of plastic and elastic displacements during the running manufacturing process. Due to the rough environmental conditions in many metalworking manufacturing processes, there are no non-invasive commercial methods for measuring the loads in the processed zone. For this reason, the suitability of speckle photography for in-process measurements of displacements to determine material loads in the process of single-tooth milling, rolling, grinding and laser hardening is investigated and questions regarding the respective achievable measurement uncertainty are addressed. To prevent a decorrelation of the speckle patterns within a measurement series, the images are captured with a high speed camera and the total surface displacement is calculated from the sum of the individual image-to-image shifts. The measurement uncertainty of the image series thus adds up slowly with the number of processed images. However, by locally averaging the image series when stitching the individual displacement fields together to form a larger overall measurement field, the measurement uncertainty in the applications under consideration can be reduced to 1% of the maximum displacement. In this context, the interrelation between the cumulative uncertainty of measurement and the lateral expansion or size of the total displacement fields under consideration is investigated. In particular, the measurement uncertainty can decrease even further, if the individual measurement fields overlap more and if the displacement fields are small in relation to the measuring field. As a result, speckle photography provides a low measurement uncertainty and shows its applicability under rough environmental conditions in the examined processes.

PROCIR-D-19-01377R2	**An approach for a reliable detection of grinding burn using the Barkhausen noise multi-parameter analysis**	**Daniel Sackmann**; Jonas Heinzel; Bernhard Karpuschewski	June 4th (14:00 -16:00, CET)
High loaded, case-hardened workpieces are often finished by grinding to meet required form tolerances and generate high-quality surfaces. The thermo-mechanical load during grinding influences the surface integrity and therefore the functional behavior of the workpieces. To increase productivity, grinding processes are often operated at their limit. Therefore, already even minor deviations from the desired process conditions can lead to thermo-mechanical damages, often referred to as grinding burn. Micromagnetic testing methods allow for a nondestructive analysis of the surface integrity of ground workpieces. Often, a combination of multiple parameters is used to get distinct results. In this study, the Barkhausen noise measurement was used for a nondestructive characterization of process specific influences on the surface integrity in order to further improve the grinding burn detection. Case-hardened workpieces made of AISI 4820 steel were finished by outer diameter grinding with varying specific material removal rates Q'w in a range of 0.5 $mm^3/(mm\ s)$ to 24 $mm^3/(mm\ s)$. Determining the resulting surface integrity, different levels of thermo-mechanical influence on the workpiece surface layer were detected. A detailed analysis of the effective Barkhausen noise (RMS value), the Coercivity and the Peak Position was performed in order to evaluate the influence of the magnetization parameters on the resulting signals depending on the surface integrity. A varying sensitivity for indication of thermo-mechanical damages with different magnetization parameters was found. The presented results allow for an improvement of the reliability of the Barkhausen noise multi-parameter grinding burn analysis.			
PROCIR-D-19-01400R3	**Non-destructive detection of machining-induced white layers in ferromagnetic alloys**	**Matthew Brown**; Hassan Ghadbeigi; Pete Crawforth; Rachid M'Saoubi; Andrew Mantle; Jamie McGourlay; David Wright	June 4th (14:00 -16:00, CET)
Machining-induced white layers are an undesirable surface integrity feature which, due to their physical properties, can have a direct effect on the in-service performance of aero-engine components. Typically, destructive methods such as cross-sectional microscopy are used during inspection to identify white layers. This is costly, both in terms of parts sacrificed and time-consumed. A non-destructive evaluation method could speed-up inspection and allow all parts to be inspected before entering service as well as throughout the component life cycle. The present work covers the quantitative characterization of machining-induced white layers in super chrome molybdenum vanadium steel through destructive methods in addition to Barkhausen noise non-destructive testing of the same surfaces. White layers formed by machining with severely worn inserts were measured to be up to 50% harder than the bulk material, possess nano-scale grains and can have an associated compressive residual stress state of up to -1800 MPa. Barkhausen noise testing was used to show that surfaces with a white layer formed by SPD could be detected by measuring shifts in the peak frequency of the Barkhausen noise signal, caused by the compressive near-surface residual stress state associated with the formation of white layers of this type.			
PROCIR-D-19-01413R3	**Influence of process chains with thermal, mechanical and thermomechanical impact on the surface modifications of a grind-strengthened 42CrMo4 steel**	**Lisa Ehle**; Rebecca Strunk; Florian Borchers; Alexander Schwedt; Brigitte Clausen; Joachim Mayer	June 4th (14:00 -16:00, CET)
Since the term surface integrity was introduced in 1964 by Field and Kahles, the final processing step and its influence on the surface microstructure was heavily investigated. In particular, a lot of research on the surface microstructure and its connection to the functional properties of the workpiece like life time and wear resistance has been performed. However, the influence of the process chain on the final surface microstructure of the workpiece was in industrial applications most of the time not taken into account, although the former manufacturing steps do affect the final result. In this work, samples of ferrite-perlite 42CrMo4 steel			

(AISI 4140) were first processed by grinding with mechanical main impact (grind-strengthening) and then mechanically, thermally and thermo-mechanically treated to investigate the change in the microstructure depending on the chosen process chain. Electron backscatter diffraction (EBSD) measurements as well as backscatter electron images (BSE), secondary electron images (SE), energy dispersive spectroscopy (EDX) and transmission electron microscopy (TEM) were used to characterize the change in the surface modifications. The first applied grind-strengthening process caused a heavily deformed surface zone of ~4 µm with nano-crystalline grains and high dislocation densities in the following ~10 µm. Thermal treatment resulted in grain growth and dislocation annihilation due to static recrystallization whereas mechanical treatment either increased the dislocation density further or decreased the dislocation density by annihilation of dislocations and dislocation rearrangement. Thermomechanical treatment resulted in small equiaxed grains in the surface zone. Cementite lamellae of perlite grains were deformed, partly dissolved and formed spherical carbides at grain boundaries in the surface zone for all process chains including thermal treatment.			
PROCIR-D-19-01414R2	**Method for process monitoring of surface layer changes in turning of aluminium alloys using tools with a flank face chamfer**	Hendrik Liborius; **Thomas Junge**; Thomas Mehner; Andreas Nestler; Andreas Schubert; Thomas Lampke	June 4th (14:00 -16:00, CET)
Lightweight materials can contribute significantly to an enhancement of energy and resource efficiency. In this context, the properties of the surface layer (e.g. residual stresses) influence the performance of machined parts considerably. However, the machining process often entails a change of the surface properties. Consequently, a predefined modification of the surface properties in final machining enables a highly efficient manufacturing of reliable lightweight components. For ensuring the required properties, the machining process has to be monitored. In the experimental investigations, stepped cylindrical specimens consisting of the aluminium alloy EN AW-2017 are machined by turning. The cutting speed is varied in the range from 50 m/min to 550 m/min. The depth of cut (0.2 mm) and the feed (0.05 mm) are kept constant. The influence of the chamfer angle of the flank face (0°, 5°, 10°, 15°) is analysed using cemented carbide indexable inserts. For process monitoring, the components of the resultant force are recorded by a dynamometer. Additionally, the voltage and the current between the tool and the workpiece resulting from the Seebeck effect are detected, enabling the measurement of the temperature near the shear zone. The geometrical properties of the machined surfaces are characterised using a tactile measurement instrument and a 3D laser scanning microscope. To determine the residual stresses, X-ray diffraction analyses of the machined surface are performed. The experimental results show that an increase of the cutting speed leads to higher Seebeck voltages between the tool and the workpiece due to elevated temperatures in the shear zone. Additionally, the surface roughness depth Rz and the built-up edge formation are reduced. Enlarging the chamfer angle results in increasing surface roughness values and decreasing absolute values of the tensile residual stresses in the tangential direction at the surface. The process monitoring allows for the implementation of real-time control adjustment of the surface layer properties during machining.			
PROCIR-D-19-01430R2	**An optical method to determine the strain field on micro samples during electrohydraulic forming**	**Dirk Stöbener**; Gabriela Alexe; Lasse Langstädtler; Marius Herrmann; Christian Schenck; Andreas Fischer	June 4th (14:00 -16:00, CET)
The surface integrity of a component usually has a significant influence on its functional properties. This applies in particular to metallic micro components with sub-millimeter dimensions where little to no core material is present. Since the surface regions of these components can also exhibit changed material properties compared to macroscopic components due to size effects, the material properties cannot be adopted directly from conventional material tests such as tensile tests on macro samples of the same material. The electrohydraulic forming process opens up the possibility of directly investigating the elongation behavior of metallic micro samples in the forming process. However, an in situ strain measurement on the deformed micro sample is required in the mold, for which no			

measurement method is known so far. For this reason, an in situ measurement approach is presented for detecting the 2D deformation field of the micro sample surface during the electrohydraulic forming process. The approach is based on the optical methods digital speckle photography and digital image correlation. They record the movement of locally characteristic surface patterns in the 0.7 mm wide forming channel through an optical access. By calculating the gradients of the local surface motion, the strain fields on the micro samples are determined. The optical access is achieved by a 10 mm thick sapphire pane, which was tight integrated into the forming die. The 2D strain field measurement of hard sample materials (e.g. bronze) can be performed with digital speckle photography that offers a higher image contrast for optically smooth surfaces, while softer materials such as aluminum tend to get smeared at the pane, so that the captured images are evaluated with the more robust digital image correlation. An assessment of the measurement method on the basis of initial measurement results shows its principle applicability for the material characterization of micro samples.			
PROCIR-D-19-01438R4	**Development of a Methodology for Strain Field Analysis during Orthogonal Cutting**	**Markus Meurer**; Thorsten Augspurger; Berk Tekkaya; Daniel Schraknepper; André Pontes Lima; Thomas Bergs	June 4th (14:00 -16:00, CET)
Functionality of all machined parts depends on their dimensional tolerance, surface condition and subsurface characteristics, which are often summarized as surface integrity. Key aspects of surface integrity are a change of the residual stress state and white layer formation. Reasons for any workpiece modification of the surface rim zone can be found in the occurring high thermo-mechanical loads during the cutting process. Over the last years, many researchers published simulation based approaches to determine both thermo-mechanical loads and changes in workpiece microstructure induced by machining. Nevertheless, the direct measurement of relevant state variables such as plastic strain and temperature fields at relevant cutting conditions is still a key challenge. Directly obtaining those state variable fields from the process will enable the development of fast computing analytical models to in-process estimate surface integrity features. As a basis for later modelling of dynamic recrystallization during cutting, a methodology to calculate the accumulated equivalent plastic strains alongside one particle movement path throughout the shear zone is developed in this paper. Therefore, an orthogonal cutting test bench has been used to obtain high resolution images when cutting AISI 4140 which were then analyzed using Digital Image Correlation (DIC).			

6.8 Topic 8: Effect of surface integrity on in-service performance of parts

ID	Title	Authors	Q&A session
PROCIR-D-19-01339R2	**Influence of residual stress depth distribution on lifecycle behaviour of AISI4140**	**Kolja Meyer**; Berend Denkena; Bernd Breidenstain; Alexandre Mendes Abrao	June 5th (14:00 -16:00, CET)
Surface integrity has a major influence on the fatigue behaviour of metallic components. Using deep rolling, the residual stress state can be influenced to a high degree under consideration of the contact stresses between workpiece and tool. This can be used to tailor the residual stress state to improve the fatigue and lifecycle behaviour of metallic components. To combine the existing knowledge about the relationship between mechanical load during deep rolling and the residual stress state and lifecycle experiments, a previously developed model is applied to quenched and tempered AISI4140 components to generate parts with similar surface residual stresses but different depth distributions. The parts are stressed using rotating bending tests and the influence of the residual stress			

state on the residual stress relaxation and lifespan is evaluated. The results show that it is possible to influence the residual stress state to a targeted profile by the adaption of the machining parameters. The performed deep rolling experiments result in two cases: Both parameter variations result in similar compressive surface residual stresses. Parameter set A (high pressure, low overlap) generates a higher residual stress penetration depth and a higher roughness, while set B (low pressure, high overlap) generates a lower penetration depth and a smoother surface. The rotating bending tests result in a higher lifetime and a lower residual stress relaxation for parameter set A.

PROCIR-D-19-01427R2	**Analysis of the Influence of Surface Integrity of Cemented Carbides Machined by Sinking EDM on Flexural Fatigue**	Thomas Bergs; **Timm Petersen**; Ugur Tombul; Andreas Klink	June 5th (14:00 -16:00, CET)

Bulk forming is a manufacturing technology characterized by high tool loads. In order to reduce form deviations and increase surface qualities this manufacturing technology aims for even higher process forces, which result in larger stresses during the forming process. Consequently, the tool life of steel tools decreases drastically. A material that offers an alternative are cemented carbides due to their ability to withstand enormous compressive stresses and their resistance to wear. However, for the same reason, cemented carbides are hard to machine with conventional cutting technologies. A cost-efficient alternative is electrical discharge machining (EDM), because of its independence from mechanical material properties. Due to the brittle character of cemented carbides, one of the challenges in EDM, the reduction of the influence on the surface integrity, becomes a paramount concern. Thermal stresses caused by machining can initiate cracks that may lead to a failure of the tool after a few load cycles. The risk of crack initiation can be reduced with an appropriate machining strategy. In order to correlate the influence of surface integrity with flexural strength, load-controlled fatigue tests are conducted with two different types of cemented carbides that have each been machined with three different EDM-strategies. Along with the fatigue evaluation, the cross sections of the specimens are examined regarding their Surface integrity. With these results it is possible to evaluate the impact of surface integrity of EDMed cemented carbides on the flexural fatigue.

PROCIR-D-19-01444R2	**Machining for an increased fatigue life for a Ti-6Al-4V ELI component**	**Pieter Andries le Roux**; Rudolph F. Laubscher; Andreas Schubert	June 5th (14:00 -16:00, CET)

Fatigue life is an important design criterion for many structural parts. The surface integrity induced by a typical machining operation may have a marked effect on fatigue life. Literature evidence suggests that the compressive surface residual stress state may change appreciably from the state obtained at the recommended conventional cutting speeds when intermediate cutting speeds are utilized. Titanium alloys typically show an increased compressive residual stress state at intermediate speeds before eventually tending towards tensile stresses at elevated cutting speeds. This paper investigates the effect of an optimised cutting strategy to control the residual stress state of a machined Ti-6Al-4V ELI (extra low interstitial) component to thereby control the fatigue life. An experimental program is conducted whereby stepped shafts are machined at various cutting speeds before being subjected to a full cyclic in-plane bending moment fatigue test. Cutting speed is varied between the typically recommended speed of 40 m/min to an intermediate speed of 110 m/min. Residual stresses are measured by XRD and compared to the fatigue life achieved. Other surface integrity descriptors including surface roughness, sub surface microstructure and selected surface damage effects are presented and discussed in relation to the fatigue performance. In essence the paper reports that fatigue life can be improved by machining at the optimum cutting speeds. These optimum intermediate speeds do however introduce other less desirable effects such as an increase in surface damage including the presence of weldments and ploughing grooves that may have a negative effect on the reliability of the improvements obtained.

PROCIR-D-19-01452R3	**Comparison of Additively Manufactured vs. Conventional Maraging Steel in Corrosion-Fatigue Performance after various surface treatments**	**Emmanouil Bouzakis**; Apostolos Arvanitidis; Fotis Kazelis; Georgios Maliaris; Nikolaos Michailidis	June 5th (14:00 -16:00, CET)
Additive manufacturing (AM) exhibits some inherent processing characteristics that affect the grain structure, phase formation, microstructure, roughness and porosity, compared to conventionally manufactured components. Consequently, the surface originating functional life, especially corrosion, can be severely affected. The present study highlights and compares the fatigue life of maraging steel 18Ni-C300 (1.2709, X3NiCoMoTi18-9-5) obtained by the SLM-fabricated specimens with the corresponding ones machined to the same geometry from a rolled bar. Metallography, microscopy, surface scanning, FEM and hardness measurements were employed to help understand the results obtained. To make a more realistic estimation of the life expectancy, fatigue was performed both in a corrosion-free environment and in a typical 3.5% wt. NaCl aqueous solution. Additionally, the effect of glass- blasting (GB) performed as a post-treatment in the SLM specimens was investigated both. There is a clear superiority of the wrought material both in pure fatigue and in corrosion-fatigue, because of its dense and homogeneous microstructure as well as its lower resulting surface roughness. The AM material, due to multiple melt pools created from the consecutive laser passes, the cellular-dendritic structure and the inherent higher roughness they possess, has an inferior fatigue and corrosion-fatigue performance. Glass-blasting improves surface integrity by imposing residual stresses and reducing the roughness, both offering a positive impact on the corrosion and fatigue performance.			
PROCIR-D-19-01705R2	**Load Capacity of Rolling Contacts Manufactured by Wire EDM Turning**	Thomas Bergs; **Ugur Tombul**; Dieter Mevissen; Andreas Klink; Jens Brimmers	June 5th (14:00 -16:00, CET)
Previous investigations have shown that load carrying capacity of gears manufactured by wire EDM is three times higher than ground gears for short time contact fatigue tests. Typical EDM surfaces are characterized by discharge craters, which lead to beneficial running-in topography formation. Investigations of tooth flank load-carrying capacity of specimen represent the tribological performance of rolling contacts. In gear testing, a tribological comparable disk-on-disk test is performed to reduce effort and costs during machining gears with complex geometries. For this purpose, testing shafts with high geometrical accuracy and different surface qualities were manufactured by wire EDM on a single-axis rotary indexing table. Following, the surface integrity and performance of these specimens on the disk-on-disk test were investigated focusing on short time contact fatigue strength and running-in behavior.			

6.9 Topic 9: Modelling of the surface integrity generated by finishing processes

ID	Title	Authors	Q&A session
PROCIR-D-19-01336R2	**Prediction of Surface Residual Stress on Titanium Alloy generated by Belt Grinding using Molecular System Dynamics**	Yun Huang; Shuai Liu; **Guijian Xiao**; Yi He; Wenxi Wang; Wentao Dai	June 5th (14:00 -16:00, CET)
With the reason of its high strength, good corrosion resistance and high heat resistance, titanium alloy has been widely used in aeronautical field, especially in aero-engine design. Because of the characteristics of cold state and flexibility, belt grinding is one of the effective titanium alloy finishing. However, the variation			

of residual stress with grinding parameters in the belt grinding process are not clear, which greatly limits the further application of this method. In this paper, based on the knowledge of molecular system dynamics, a molecular system dynamics model of residual stress on the surface of abrasive belt grinding of titanium alloy is established. Based on the corresponding intermolecular potential function of titanium alloy material, a linear regression equation is established, and the expression of residual stress at molecular level on the surface of belt ground titanium alloy was obtained. The model is simulated with MATLAB, and the results are in good agreement with the intermolecular potential model. Through relevant experiments, the experimental results are compared with the simulation results of titanium alloy molecular system, the error is analyzed and the conclusion is given. When the grinding linear velocity is 8-24 m/s and the feed velocity is 20-60 m/ min, the residual stress of TC17 alloy belt grinding is - 169 to – 254 MPa, and the model prediction error is within 20%.

PROCIR-D-19-01364R2	**Modeling and analysis of residual stress in dynamic orthogonal cutting**	Zhihao Deng; Xiaoming Zhang; **Zhengyan Yang**; Dong Zhang; Han Ding	June 5th (14:00 -16:00, CET)

This work develops a predictive model to explore the influence of vibration on residual stress during orthogonal cutting process. The first part involves the design of a low-speed dynamic cutting setup and a measuring device of chip thickness and cutting forces. The second part established an analytical model to calculate the mechanical load in the primary shear zone and tertiary shear zone by using the experimental measurements. Finally, the equivalent moving mechanical load is applied to the workpiece based on the birth-death element method to predict the residual stress without the need to consider the tool-workpiece contact. The simulations show that the vibration has a significant effect on residual stress, and experimental validations will be conducted in the next stage.

PROCIR-D-19-01365R4	**Experimental and numerical study of the subsurface deformation and residual stress during the roller burnishing process**	**Dong Zhang**; Xiaoming Zhang; Han Ding	June 5th (14:00 -16:00, CET)

Roller burnishing process is being extensively used to enhance the fatigue life of the aircraft engine components by introducing compressive residual stress and work hardening. The temperature rise during the burnishing process could be neglected due to the low friction rolling contact between the roller and workpiece, thus simplifying it an elastoplastic deformation process. In this paper, the digital image correlation technique was adopted to obtain the subsurface deformation field during the roller burnishing process. A 3D finite element model was built up to simulate the burnishing process. The predicted surface integrity parameters including subsurface deformation and residual stress are compared with the experimental measurements.

PROCIR-D-19-01367R2	**A physically based model of *Ti6Al4V* turning process to predict surface integrity improvements**	**Sergio Rinaldi**; Giovanna Rotella; Domenico Umbrello; Luigino Filice	June 5th (14:00 -16:00, CET)

In turning processes, surface improvements are strictly related to the physical phenomena induced by the involved thermo-mechanical loads. These phenomena are difficult to be analyzed while they occur, therefore the process simulation is a very important tool to deeply understand their evolution. Turning experiments were carried out on Ti6Al4V workpiece under different machining conditions. The microstructural modifications were analyzed in terms of metallurgical changes and micro-hardness. The physical mechanisms that occurred on the machined surface were investigated to construct a constitutive material flow model. The developed material model was implemented via sub-routine in a commercial FE software and validated through comparisons with experimental data (cutting forces, temperatures and microstructural modifications). The model was employed to predict the process variables of scientific interest (microstructural changes and surface improvement). The numerical results in main cutting forces, feed forces and temperatures prediction proved the accuracy and reliability of the proposed numerical model showing a good agreement with the experimental data.

PROCIR-D-19-01378R3	**Forming mechanisms based simulation and prediction of grinding surface roughness for abrasive belt rail grinding**	Chaoyue Zhao; Jianyong Li; **Wenxi Wang**	June 5th (14:00 -16:00, CET)

Abrasive belt rail grinding (ABRG) was recently applied to repair the contour of the rail and eliminate the surface damage of the rail. Besides, it is desirable to not only suppress the occurrence of new damage but also to improve driving comfort and reduce wheel-rail wear. The surface roughness of the rail directly affects the contact noise, vibration, friction, and wear of the wheel-rail. However, due to the complicated contact state in belt grinding, the surface roughness forming mechanisms are still unclear. Therefore, it is necessary to study the influence of ABRG on surface roughness and to obtain a prediction method for roughness. In this paper, the initial morphology of the abrasive belt was created by using 2D digital filtering technology. The discretization method was used to simplify the entire belt grinding process into several local surface grinding processes carrying different contact pressure. The grinding depth of the abrasive particles on the local abrasive belt at various times was calculated, and the envelope of the cutting edge was induced according to the grinding depth of the effective abrasive grits. The roughness simulation of ABRG based on the forming mechanism was realized, and the 2D roughness of the processed surface was investigated. The good consistency between simulation and experimental results successfully proved the validity of the proposed method, and they both show that the contact forcé has a significant positive correlation to both Ra and Rsm.

PROCIR-D-19-01395R3	**Determination of residual stresses in processes with multiple thermal loads**	**Julian Vorspohl**; Friedhelm Frerichs; Sebastian Schneider; Matthias Meinke; Wolfgang Schroeder; Andreas Klink; Thomas Lübben	June 5th (14:00 -16:00, CET)

Numerical models are used to identify correlations between internal material loads and material modifications. Such correlations are called Process Signatures, which are based on the idea that different processes inducing equal internal material loads produce the same material modifications. Here, machining processes involving repeated thermal loads at high frequency as they occur in laser ablation or electric discharge machining are considered. As an example for the material modifications, the resulting residual stress distribution is determined as a function of the temperature. First, the temperature field in the work piece is computed for about 1000 consecutive heat pulses generated by the laser or electric discharges. An in-house finite-volume method is used to solve the time dependent enthalpy equation on a hierarchical Cartesian grid, which allows a high degree of parallelization such that high-performance computing hardware can be used. The resulting temperature fields and the heating rates for several load numbers are used to determine the residual stress state in the material. This is done in a second step by finding an appropriate model for the thermal loads, which provides a boundary condition for a finite element simulation of the surface near modification process. In this step, phase transformation during heating (austenite formation) and cooling (martensitic formation) are taken into account. Finally, the displacements and residual stresses are calculated by the phase and temperature distributions determined in the previous step. The results are compared with measurements and enable the determination of a Process Signature component describing the relation between repeated heat loads and the resulting residual stresses in the surface layer of the work piece.

PROCIR-D-19-01401R3	**A simulation-based analysis of internal material loads and material modifications in multi-step deep rolling**	**Tobias Kinner-Becker**; Jens Sölter; Bernhard Karpuschewski	June 5th (14:00 -16:00, CET)

The concept of Process Signatures states that material modifications are solely dependent on the acting internal loads during processing, irrespective of the specific process chosen. Knowledge of these correlations would allow the prediction of the resulting surface integrity of a process and consequently facilitate the process design. The validity of the concept was already shown for single-step processes in the past. However, more relevant to industrial praxis are multi-step processes with recurring loadings of the workpiece material under varying conditions. In those, the internal loads during a specific step interact with previously generated modifications. This has to be taken into account in the formulation of industrially relevant Process Signatures. In the present paper, 3D finite element simulations are utilized to examine the influence of recurring loadings for deep rolling. Prismatic workpieces made of 42CrMo4 (AISI4140) are deep rolled along consecutive tracks with different overlaps of the paths. The development of the internal material loads and the residual stresses of consecutively deep rolled tracks is determined and qualitatively compared with experimental results. The observations help to better understand the material behavior during multi-step deep rolling and are the starting point for further analyses to derive Process Signatures that incorporate the influence of recurring loads.

PROCIR-D-19-01404R3	**Influence of Initial Microstructure on Manufacturing Processes with Thermal Loads accompanied by Hardening**	**Friedhelm Frerichs**; Thomas Lübben	June 5th (14:00 -16:00, CET)

The presented investigation focuses on the correlation between concrete physical loads and resulting modifications. The physical and in a wider sense chemical loads are called internal material loads. The correlation between the generated internal material loads and the modifications is called Process Signature. This contribution presents some Process Signature components for thermal dominated processes with phase transformation and accompanying hardening. The selection of the Process Signature components considers the residual stress state at the surface and the positions of the zero crossings of the residual stress curve. Based on Finite Element simulation and experimental work the external thermal loading of both processes were characterized by the resulting maximal temperature and temperature gradient, which correlates with the change of the residual stress state. During the CIRP CSI conference 2018 in Tianjin the authors presented results for the mentioned Process Signature components for a ferrite/perlite state. The actual work focuses on the question, how the above described Process Signature components depend on the initial microstructure of the steel. For this purpose the phase kinetics of different initial quenched and tempered states are investigated for fast heating processes up to 5000 K/s. Additionally the mechanical materials properties of these material states will be presented.

PROCIR-D-19-01439R2	**Residual stresses prediction in machining of Inconel 718 superalloy using a constitutive model considering the state of stress**	**Francisco A. V. da Silva**; Lamice A. Denguir; José C. Outeiro	June 5th (14:00 -16:00, CET)

The need for developing new products that meet high functional requirements, such as high fatigue strength, superior thermal and corrosion resistance, have permitted to focus on the development of enhanced materials and seek solutions that also promote better surface integrity. It is the case of the Inconel 718 nickel superalloy, where the combination of its mechanical and thermal properties provides a full industrial application, especially in hot engine components in the aerospace industry. However, there is still a big challenge to obtain suitable surface integrity for this kind of application after machining this alloy. This work aims to predict the surface integrity in the machining of the Inconel 718 alloy using an orthogonal cutting model implemented in Abaqus FEA software. This model includes a constitutive model considering the most relevant factors affecting the mechanical behavior of Inconel 718 in machining, including the strain rate and the state of stress. The machining model is validated by comparing the measured and predicted results. Then, it is used to evaluate the influence of the cutting regime parameters and tool geometry on the residual stresses.

PROCIR-D-19-01443R2	**Sensitivity analysis of the input parameters of a physical based ductile failure model of Ti-6Al-4V for the prediction of surface integrity**	**Gorka Ortiz-de-Zarate**; Andres Sela; Aitor Madariaga; Thomas H. C. Childs; Pedro José Arrazola	June 5th (14:00 -16:00, CET)

In machining of Ti-6Al-4V, it is commonly reported the appearance of segmented chip produced by adiabatic shearing (at high cutting speeds) and lack of ductility (at low cutting speeds). Moreover, machining is a manufacturing process that is based on applying external energy to the workpiece to produce a separation of a material layer. Thus, to analyze the physics involved in the new surface generation and in the chip segmentation process, it is necessary to apply ductile failure models. However, the characterization of fracture models in machining conditions (temperature, strain rate, stress triaxiality, Lode angle etc.) is an arduous task. Therefore, to define a ductile failure model applicable to machining it is almost inevitable to apply inverse simulations strategies to obtain reliable results in the not tested conditions. Nevertheless, there is few information about the influence of the input parameters of ductile failure model in fundamental outputs and even less in surface integrity aspects. The aim of this research was to conduct a sensitivity analysis of the influence of the input parameters of a physical based ductile failure model not only in fundamental variables (forces, temperatures and chip morphology) but also on surface integrity (surface drag). To this end, a subroutine was developed for the ductile failure model and it was implemented in the Finite Element Method (FEM) software AdvantEdge. Subsequently, using a statistical software and the Design of Experiments (DOE) technique the influence of the input parameters of the failure model on the outputs was analyzed.

PROCIR-D-19-02217R3	**Finite element simulations of the material loads and residual stresses in milling utilizing the CEL method**	**Andrey Vovk**; Jens Sölter; Bernhard Karpuschewski	June 5th (14:00 -16:00, CET)

Within the process chain for the production of highly stressed components, finishing is of particular importance - the resulting surface layer properties of the workpiece decisively determine the component functionality. According to the concept of Process Signatures proposed by Brinksmeier and others, in the present work the internal material loads and the resulting material modifications are analyzed for milling of quenched and tempered 42CrMo4 (AISI 4140). 3D finite element simulations were conducted utilizing the Coupled Eulerian-Lagrangian (CEL) method for which remeshing can be omitted. This is u.a. because the stresses during the process can not be measured in the required temporal and spatial resolution. Therefore, in this work, 3D finite element simulations are used to investigate the influence of repetitive stress on hard milling. The formation of stresses at variable tooth feed, but with constant cutting speed and depth of cut is investigated. The development of material modifications (residual stresses) due to multiple stresses was determined and compared with experimental results. Results from the simulation show good accuracy in comparison with the experimentally determined cutting force and active force. The use of the CEL method in the simulation of milling allows us to determine the stresses in sufficient spatial and temporal resolution without the use of remeshing.

PROCIR-D-20-00053R2	**Predicting the induction hardened case in 42CrMo4 cylinders**	**Maialen Areitioaurtena**; Unai Segurajauregi; Iker Urresti; Martin Fisk; Eneko Ukar	June 5th (14:00 -16:00, CET)

Induction hardening has the potential to produce favourable surface integrity that can improve fatigue performance and extend the lifetime of a component. The localized superficial heating provided by induction is the main advantage of this process, as it allows the core to remain intact and, therefore, ductile, while the surface is hardened. Achieving favourable characteristics in the hardened case is of great importance, as this process is usually applied to load bearing and wear-susceptible metallic components. The simulation of the hardening process by induction heating is a complex and challenging task at which many efforts

have been directed in the last years. Due to the numerous interactions of the many physics that take part in the process (electromagnetic, thermal, microstructural and mechanical), a highly coupled finite element model is required for its numerical simulation. In this work, a semi-analytical induction heating model is used to compute the induction hardening process, predicting the size and shape of the hardened layer and the distribution of the hardness. Using the semi-analytical model allows the computational time to be much faster compared to a fully coupled model using a commercial software, where the time consumption for the presented 2D case is reduced by 20 %. Experimental validation is presented for cylindrical 42CrMo4 billets heated by a short solenoidal inductor, which shows good agreement with the predicted results, reaching an average error of 3.2 % in temperature estimations.

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