PPI
Polymer Process Innovation

Abstract Book

Edited by

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4th International Conference on Polymer Process Innovation (PPI)

18 – 20 of September, 2024
Ghent University, Ghent, Belgium

Editors:

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About PPI Conference

This volume constitutes the proceedings of the 4th International Conference PPI Conference ‘PPI 2024 – Polymer Process Innovation’ held from the 18th to 20th of September, 2024, at Ghent University. This Conference is intended to bring together the researchers, engineers and technologists working in the various fields of Polymer Engineering addressing issues in the areas of new material applications and innovative tooling. More than 70 contributions, coming from various continents, will attend the ‘PPI 2024’ edition. We sincerely thank all the participants from academia, research centres and industry, for their commitment and work on writing their manuscripts that are the basis of the established scientific soundness of the PPI conferences. The conference programme included 5 Plenary lectures, 53 Oral presentations and 16 Posters. This volume of the Proceedings contains the abstracts that passed the reviewing process, and cover an extensive range of scientific and technical topics of Polymer Engineering and Technologies. The topics of the sessions include Polymer Recycling, Polymer Processing Simulations, Development in Polymer Processing, Sustainable use of polymers, Polymer Rheology, Additive Manufacturing, Moulds and Mould Making innovations, Trends in Product Development and Polymer Composites.

Much of the success of ‘PPI 2024’ is due to the contributions of many dedicated colleagues. We wish to express our sincere grateful thanks to:

• The invited speakers for the Plenary lectures, who contributed to highlight some of the most present and exciting research topics in the Polymer Engineering;

• The International Scientific Committee, for their help in publicizing the Conference, and the efficiency in the reviewing process of the manuscripts with their valuable comments;

• The Local Organizing Committee who contributed with their experience and expertise in promoting and coordinating the many activities for the organization and smooth running of the conference.

A final and very special thank is for the financial support of our sponsors, namely Ecoo, Fonds Wetenschappelijk Onderzoek (FWO), Benelux Scientific, Simpatec, Engel, Thermofischer, Xplore, Anton Paar and of course Ghent University and KU Leuven.

The publication of these proceedings will make justice to all who contribute to the running of a well participated conference in the fields of Polymer Process Innovation in Ghent, Belgium. The broad coverage of well-established and emergent topics in the field is a strong contribution to the promotion of international cooperation and establishment of synergies for the development of Polymer Engineering.

Scientific Committee – Chairmen

Ludwig Cardon

Full professor at the Department of Materials,
Textiles and Chemical Engineering
at Ghent University
Head of the Centre for Polymer and Material Technologies (CPMT)

Ludwig Cardon obtained his PhD in Engineering in 2006 at Birmingham City University, after a long career in supporting industry for polymer engineering, technology, and design and prototyping. Currently, he is full professor at Ghent University and head of the Centre for Polymer and Material Technologies (CPMT) within the department of Materials, Textiles and Chemical Engineering. He is specialized in additive manufacturing and polymer processing, with a specific focus on sustainability, extrusion-based and powder-bed fusion technologies, biopolymer blends and mould engineegin. He has published ca. 100 peer-reviewed full-length research articles, participated in >150 conference contributions of which >30 invited keynotes. He is author and co-author of 8 book chapters and 3 granted patents. He is/was coordinator of national and European funded research projects, several of them in cooperation with industry. He is associate editor of the engineering journal “Plastics Rubbers and Composites – Macromolecular Engineering”. He is also the co-founder of the joint laboratory on Additive Manufacturing and Advanced Materials together with Sichuan University, China, and co-founder of the UGent spinoff MakinH dealing with sustainable product development and manufacturing.

António J. Pontes

Associate Professor in the Department
of Polymer Engineering at the University of Minho
CEO and Founder of the DONE Lab

António J. Pontes is Associate Professor w/ habilitation at Department of Polymer Engineering since 2002, with a PhD in Polymer Processing and Design. He develops its teaching and research activities in the areas of design and development of polymeric products and nonconventional processing of polymers. He was Director of the Degree in Polymer Engineering (Jan 2003 - Jan 2007) and Departmental Coordinator of Socrates/Erasmus program (Jan 2003 - Dec 2004). He is author or co-author of 20 book chapters and more than 250 scientific publications (including articles in international journals and conferences). He is author or co-author of 21 patents, 15 being international. He coordinated more than 40 research projects (with national and European financial funding) including with industry. Is the responsible since 2012, from UMinho side, of the partnership coordination Bosch-UMinho. Between Jan 2011 to Feb 2013 he was Director of the Polymer Engineering Department and between March 2013 and February 2015 was Deputy Director. Between Oct 2013 and February 2016 was Deputy Director of the Institute for Polymers and Composites. He serves on the Board of Directors of the Centre for Innovation in Polymer Engineering, PIEP, since March 2013. CEO and Founder of the DONE Lab – Advanced Manufacturing of Products and Tools.

Costas Charitidis

Professor at the School of Chemical Engineering,
National Technical University of Athens
Director of the Laboratory of Advanced,
Composite, Nano Materials & Nanotechnology

Costas Charitidis is Professor in the School of Chemical Engineering of the National Technical University of Athens and Director of the Laboratory of Advanced, Composite, Nano Materials & Nanotechnology. He is member of the Scientific Council of the Hellenic Foundation for Research and Innovation. He has been elected in the Deanship of the School of Chemical Engineering of NTUA since 2017. From 2010 to 2016 he has been Director of Section III: Materials Science & Engineering of the School, while from 2011 he is Director of the Interdisciplinary Postgraduate (MSc) Program: Materials Science & Technology (NTUA). He has more than 25 years of experience in the fields of Materials Science & Nanotechnology, Carbon-based materials and Safety impacts of Nanotechnology. He has extensive R&D experience through collaborations with international research centers since he has participated in more than 60 European and National funded projects, in many of them as Scientific Coordinator (most recent are: Nanotechnologies, Advanced Materials, Advanced Manufacturing and Processing, Resource Efficient Economy with a Sustainable Supply of Raw Materials NMP FP7, Horizon 2020). He is a referee in International scientific journals, evaluator & scientific advisor of R&D projects. He is the author of several scientific books, chapters in international text books and more than 400 scientific publications in peer reviewed international journals and conference proceedings and cited ~8200 by other researchers (h-Index 45).

Phil Coates

Professor of Polymer Engineering at the University of Bradford
Director of the Polymer Interdisciplinary Research Centre (IRC)

Professor Phil Coates is a Physics graduate of Imperial College, London. His PhD research was on solid phase deformation processing of polymers (Leeds University) with Prof Ian Ward FRS. He joined the University of Bradford in 1978 and has been Professor of Polymer Engineering from 1990. Prof Coates was elected a Fellow of the Royal Academy of Engineering in 1995. He was Pro Vice Chancellor for Research & Knowledge Transfer at the University of Bradford for 7 years (2004-11). He is Director of the internationally recognised Polymer Interdisciplinary Research Centre (IRC) which is at the leading edge of polymer engineering research, in a 4500 m2 laboratory. His research targets structuring of polymers via processing, for enhanced properties leading to high value polymer products for a range of sectors – healthcare technology (inc. oriented bioresorbable polymers for orthopaedic fixations with shape memory, and arterial stents; ultraprecision moulding; larger scale oriented polymer technologies for built environment and biaxially oriented pipes; pharmaceuticals processing; advanced materials developments, including nanocomposites and reactive processing, and upcycling routes for polymers. He pioneered a wide range of in-process measurement sensors and techniques, and computer modelling. He co-directs 3 joint international research laboratories in China and directs the Science Bridges China platform and the UK-China Advanced Materials Institute. He was honoured with the Chinese National Science & Technology Award for International Cooperation (2017), presented by President Xi Jinping and other Chinese leaders in January 2018 – China's highest honour for foreign scientists - and the 70th Anniversary Award of the PR China in October 2019. He received the Institute of Materials Netlon Gold Medal for Innovation in Polymer Processing (1999); the Plastics Industry Award for personal contribution to the industry (2006); the IOM3 Swinburne Award (2008), the Tianfu Friendship Award of Sichuan Province (2015); the Sichuan International Cooperation Award (2106); the JL White International Innovation Award of the International Polymer Processing Society (2017); the National Science & Technology Award for International Cooperation of the People's Republic of China (2017); the International Award 2018 of the Society of Plastics Engineers. He is an honorary Professor of Sichuan University (2008 on) and of Beijing University of Chemical Technology (2009 on); and Molecular Sciences Forum Professor at the Institute of Chemistry, Chinese Academy of Sciences, Beijing (2008) and CIACAS Changchun (2009), he was the first 'High End Foreign Scholar' of Sichuan University. He is a Fellow of the Royal Academy of Engineering (1995), the Institute of Mechanical Engineers (1990), the Institute of Materials Minerals and Mining (1986), and the International Polymer Processing Society (2022).

Clemens Holzer

Head of Polymer Processing and
Full Professor at Montan universitaet
Leoben (MUL)

He studied polymer engineering and science (PES) at the Montan universitaet Leoben MUL, Austria. Eight years he worked in Switzerland in the industry (Huber+Suhner, research engineer - head of a research group - Head of Production - Head of Research and Development in a business unit). After his industrial career he moved to the University of Applied Sciences North Western Switzerland FHNW, Olten and Windisch, as deputy head of the Institute of Polymer Nanotechnology INKA and associate professor at the FHNW. Since 2009 he is head of Polymer Processing and full professor at MUL. Main research themes are injection moulding, extrusion, recycling, additive manufacturing and determination of material data. From 2009 to 2010 he was the leading manager of the new building “Center for PES”. In 2010 he founded the Department of PES and was the head of it for the first 3 years period. He is member of the strategy board at Polymer Competence Center Leoben PCCL, cooperating closely with the Kunststoffcluster and Ecoplus in Austria, member of the board of the Österreichischer Carbon Cycle Circle ÖCC2 and active member of the Austrian Scientific Society for Production Engineering ÖWGP. International he is e.g. the representative for Austria in the Polymer Processing Society PPS and board member of the Wissenschaftlicher Arbeitskreis Kunststofftechnik WAK, Germany.

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CPMT - UGent Research Group

PPI 2024

Programme

18^{th} of September

DAY 1

The welcoming day and Open-Lab of the Polymer Process Innovation Conference 2024 will be held at the Centre for Polymer and Material Technologies (CPMT) at Campus Ardoyen of Ghent University.

During the Open-lab day, we will organize visits to polymer processing and analysis facilities of CPMT, demonstrate our analytical and processing equipment, and present our research projects, in cooperation with PPI gold sponsors.

Please welcome!

Day 1 – Wednesday 18-09-2024	
15:00 – 18:00	REGISTRATION @ CPMT entrance hall
	Open Lab Day @CPMT Ghent University
17:00 -18:30	Welcome reception

19th of September

DAY 2

Day 2 – Thursday 19-09-2024	MORNING	
08:30 – 09:00	REGISTRATION	
09:00 – 09:20	OPENING	
	Room 1	**Room 2**
	PLENARY	
09:20 – 10:00	Circularity indicators to assess the circularity in plastic products across different industries and applications - **Carla Martins** (UMinho PT)	
	POLYMER RECYCLING 1	POLYMER PROCESSING SIMULATION 1
10:00 – 10:20	Single screw vs Twin screw extrusion of post-consumer PP packaging waste - **Sam Haenen** (KULeuven BE)	Coupled Matrix Monte Carlo Modeling to Support Polymeric Composite Production, Polymer Modification and Recycling - **Yoshi W. Marien** (UGent BE)
10:20 – 10:40	Investigation of the silver streaks dependence on process conditions in the injection molding of post-consumer recycled polypropylene - **Anna Bortoletto** (UPadova IT)	Optimization of Injection Molding using AI: Numerical Modelling and Surrogate Models based on ANN - **António Gaspar-Cunha** (UMinho PT)
10:40 – 11:00	Upcycling of regenerates and injection moulding through a new technological approach - **Zahra Shahroodi** (ULeoben AT)	Numerical analysis of conformal cooling channels for small injection moulding inserts produced by additive manufacturing - **Ana C. Lopes** (UMinho PT)
11:00 – 11:30	COFFEE	
	POLYMER RECYCLING 2	POLYMER PROCESSING SIMULATION 2
11:30 – 11:50	Material Characterisation of Industrial Textile Waste - **Ivica Duretek** (ULeoben AT)	Development of a theoretical prediction model for coefficient of friction - **Ângela R. Rodrigues** (UMinho PT)
11:50 – 12:10	Recycling the unrecyclable: Analyses of recycling opportunities in the winter sport industry - **David Zidar** (ULeoben AT)	Micro Injection molding of polypropylene parts: morphology distribution dependence on the molding conditions - **Sara Liparoti** (UNISA IT)
12:10 – 12:30	Virgin/recyclate Blends Performance Improvements for Rotomoulding - **Peter Martin** (QUB UK)	New approach to design conformal cooling channels (CCC) through 2D simulation - **Daniel Porto** (UFSC BR)
12:30 – 13:30	LUNCH BREAK	

Day 2 – Thursday 19-09-2024		AFTERNOON
	Room 1	**Room 2**
	PLENARY	
13:30 – 14:10	From melt- to solid-stage polycondensation: how to revolutionize the design of sustainable polymers with advanced properties **- J M Raquez** (UMons BE)	
	DEVELOPMENTS IN POLYMER PROCESSING 1	SUSTAINABLE USE OF POLYMERS
14:10 – 14:30	Connecting Experimental and modeling approach for grafting of poly(lactic acid) during reactive extrusion - **Simon Debrie** (UGent BE)	Thermoforming of biocomposites with agrifood wastes and essential oils - **Ana F. Costa** (UMinho PT)
14:30 – 14:50	Developing Recycling Strategies for Expanded Polystyrene Packaging - **Mariana Vala** (UAveiro PT)	Enabling Closed Loop Plastics Processing - **Tiago E. P. Gomes** (UAveiro PT)
14:50 – 15:10	Correlation of Stereo DIC and Thermographic Imaging to Monitor Vacuum-Assisted Thermoforming of Thermoplastic Sheets - **Rasoul Varedi** (KULeuven)	Development of an underwater pelletizer for obtaining extruded recycled expanded polystyrene beads - **Carlos M. Correia** (UAveiro PT)
15:10 – 15:40	COFFEE	
	PLENARY	
15:40 – 16:10	Plastics Circularity: Fundamentals and Challenges **- Herman Van Roost** (Styrenics Circular Solutions)	
	DEVELOPMENTS IN POLYMER PROCESSING 2	POLYMER RHEOLOGY
16:10 – 16:30	Development of a production methodology based on rheological parameters for robotic extrusion additive manufacturing of thermoplastic materials - **Artur Costa** (UMinho PT)	Experimental viscosity measurements on gas-laden polymer melts - **Ward Vandaele** (KULeuven BE)
16:30 – 16:50	Insights into kinetics and mechanism of polymerization reactions via inline Raman spectroscopy - **Stanislav Kasakov** (Thermofischer BE)	Advancing Mechanical Performance of 3D Printed Lattice Structures via Rheological Optimization: A Doehlert Experimental Design Study - **Laia Farras-Tasias** (UGent BE)
16:50 – 17:10	Long chopped natural fiber biocomposites: Micro-Processing and characterization - **Nursel Karakaya** (Xplore)	Comparative study on PA12 and PA11 degradation for HP Multi Jet Fusion process - **Chiara Fiorillo** (UGent)
17:10 – 17:30	Morphology, conformation, and thermal-mechanical properties development in solid-state processed Polymer materials - **Davide Nocita** (UoB UK)	Additive Manufacturing sensor design for energy harvest and action recognition - **Maofan Zhou** (UGent BE)
	END OF DAY 2	
Evening	CONFERENCE DINNER	

20th of September

DAY 3

Day 3 – Friday 20-09-2024		MORNING
08:30 – 09:00	REGISTRATION	
	Room 1	**Room 2**
	PLENARY	
09:00 – 09:40	Additive Manufacturing of Polymer Covalent Adaptable Networks **- Xia Hesheng** (SCU CN)	
	ADDITIVE MANUFACTURING 1	MOULDS AND MOULD-MAKING INNOVATIONS A
09:40 – 10:00	Mechanical Recycling and stabilization of ABS from post-consumer Electric and Electrical Equipment (EEE) waste for filament production for FFF applications - **Christina Podara** (NTUA GR)	Assessing Geometric Deviations in Plastic Parts: A Study between Conventional and Conformal Cooling Channels in Metal Molds Produced by Additive Manufacturing - **Alexandre M. Popiolek** (UFSC BR)
10:00 – 10:20	A preliminary study on the flow-induced crystallization phenomenon in 3D printing of Polyvinylidene fluoride - **Erika Lannunziata** (UTorino IT)	Balancing heat extraction rates on injection moulding tools through smart temperature control design - **Sofia B. Rocha** (UAveiro PT)
10:20 – 10:40	Charaterization and Computational modelling of 3D printed structure via fused filament fabrication - **Yiyun Wu** (UAveiro PT)	Optimizing Ejection of PLA-Based Compounds from Hot Core-Shell Molds: Experimental Investigation and Process Modelling - **Hadi Saniei** (UNISA IT)
10:40 – 11:00	L-PBF of aluminium: mass reduction and hybrid manufacturing of an aeronautic part - **António J. Pontes** (UMinho)	Developments in the Rotational Moulding of Hydrogen Tank Liners - **Alex Pritchard** (QUB UK)
11:00 – 11:30	COFFEE	
	ADDITIVE MANUFACTURING 2	MOULDS AND MOULD-MAKING INNOVATIONS B: Hybrid Moulds
11:30 – 11:50	Design for additive manufacturing - **Sampaio, A. M.** (UMinho PT)	Influence of different surface coatings on polymeric inserts for hybrid injection molding of reinforced PBT - **Sérgio J. Rodrigues** (UMinho PT)
11:50 – 12:10	Process and material guidelines for large-scale additive manufacturing in part production: a case study between PP and ABS - **Afonso Santos** (UMinho PT)	Study of thermoplastics polymers applied to the extrusion additive manufacturing for naval industry moulds - **P.J. Novo** (IPLeiria PT)
12:10 – 12:30	PLLA phase study by Fused Filament Fabrication - **Artur Baeta** (UAveiro PT)	Investigation of the injection molding process using different concepts of molds: i) conventional cooling, ii) conformal cool-ing, iii) molds with high thermal conductivity (CuBe). - **Janaína de Carvalho** (UFSC BR)
12:30 – 13:30	LUNCH BREAK	

Day 3 – Friday 20-09-2024		AFTERNOON
	Room 1	Room 2
	PLENARY	
13:30 – 14:10	Hybrid flax and self-reinforced PLA (Polylactic acid) non-woven preform for lightweight biocomposites - **Chung-Hae Park** (IMTNordEurope FR)	
	TRENDS IN PRODUCT DEVELOPMENT 1	POLYMERIC COMPOSITES 1
14:10 – 14:30	Study of pine resin collection bag properties to develop a more environmentally friendly system - **Rita Fonseca** (IPLeiria PT)	Exploring the Thermal and Mechanical characteristics of Polymers with Recyclable Fillers: A Case Study – **Pedro Martinho** (IPLeiria PT)
14:30 – 14:50	How do we go from PO (Polyolefins) in PMD bags in Belgium to recycled products? - **Veerle Balcaen** (ECOO)	Manufacturing of PA-based filaments reinforced with chopped carbon fibres for 3D printing applications - **Artemis Kontiza** (NTUA GR)
14:50 – 15:10	Advanced design of meta-structures through additive manufacturing: A Review - **João Ferreira** (UAveiro PT)	Biopolymer filament with coffee silver skin for Fused Filament Fabrication (FFF) printing - **Ana C. Machado** (UMinho PT)
15:10 – 15:40	COFFEE	
	TRENDS IN PRODUCT DEVELOPMENT 2	POLYMERIC COMPOSITES 2
15:40 – 16:00	PLA degradation during single screw extrusion: predicting the effect of PLA-grade, die geometry and screw design on the molecular weight - **Ineke Velghe** (KULeuven BE)	Sustainable carbon fiber precursors produced from lignin blended with biobased polyamides - **Sofie Huysman** (Centexbel BE)
16:00 – 16:20	Design and Development of a Capillary Blood Collection Device for Global Disease Diagnosis and Monitoring - **José Almeida** (UMinho PT)	Design For Manufacturing – The Integrated Workflow – **Victor Tsai** (Simpatec)
16:20 – 16:40	CLOSING CEREMONY PPI 2024	

Poster Exhibitions

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Jitendra Seregar, Peter Martin, Mark McCourt and Mark Kearns
'Development of Simulation Models for the Optimisation of Type IV Hydrogen Tanks'

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- P2471

Hannelore Ohnmacht, Jie Zhang and Ludwig Cardon
'Effect of multiflow vibration injection molding on the filler dispersion and thermal conductivity of polyethylene composites'

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- P2473

Ellen Fernandez, Jie Zhang and Ludwig Cardon
'Increased impact toughness of mass polymerized ABS by tuning polymer orientation via vibration injection moulding'

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Plenary speakers

Professor dr. Carla martins

Carla Martins is Assistant Professor in the Department of Polymer Engineering at the University of Minho. She holds a PhD in Polymer Engineering from the University of Akron, USA (2004), a Master in Math Applied to Mechanics (2001) and a graduation in Polymer Engineering (1998), both from the University of Minho. She has been the director of the Integrated Master in Materials Engineering (2012-2015) and Polymer Engineering (2017-2023).

She has a vast lecturing experience in the field of polymer processing, characterization and quality control. She experienced Erasmus teaching mobility in Belgium (Gent University), France (Ecole de Mine de Douai), Colombia (Universidad Nacional de Colombia) and Turkey (TUBB University of Economics and Technology).

She is a research fellow at IPC - Institute for Polymers and Composites at the University of Minho with research interests in the areas of processing, structure and properties of polymeric materials, composites and nanocomposites and most recently focusing on the circular economy of plastics and the search for circularity indicators used as sustainability analyses, to apply to products, processes or companies. Over the course of her carrier, she participated in different scientific and industrial projects and contributed to numerous publications within the research area of polymer processing. She has supervised 3 PhD's and over 70 Master's students and authored/co-authored more than 50 scientific publications (including articles in international journals and conferences).

Professor dr.Jean-Marie Raquez

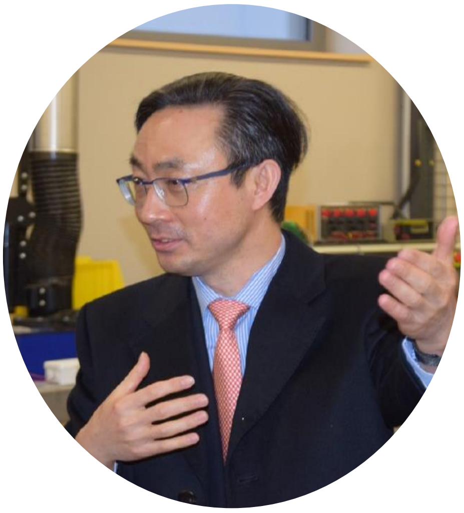
Dr. Jean-Marie Raquez received his PhD degree in Polymer Chemistry from the University of Mons-Hainaut, Belgium in 2003. He started a Postdoctoral fellowship at Michigan State University, U.S.A in 2004 and became an Assistant researcher at Materia Nova, Belgium in 2005. He became an Associated Professor at Ecole Des Mines de Douai, France in 2007 and continued his work on polymeric nanocomposites as a postdoctoral researcher at the University of Mons, Belgium in 2008. In 2012 Dr. Jean-Marie Raquez became a Scientific Advisor at Materia Nova – Research Center, Belgium and a Senior Research Associate at the University of Mons, Belgium. He became the Head of the Lab. of Polymeric and Composites Materials at the University of Mons, Belgium in 2018.

Research interest and expertise include Polymeric and composite materials, development of biobased polymeric (nano)composites and he has been a Main lecturer at the University of Mons since 2012. He has published over 190 Peer-reviewed papers, 2 books, 11 book chapters and authored 11 patents.

Professor dr. Hesheng Xia

Prof Hesheng Xia received his PhD degree from Sichuan University, China in 2001. In 2003-2005, he worked as a research associate at Loughborough University, UK. He became a full professor at Sichuan University since 2005. He is an international representative of Polymer Processing Society (PPS), and also an affiliated professor at the Institute for Polymers, Composites and Biomaterials (IPCB-CNR), Italy. His main research interests include polymer micro/nano-composites, polymer materials for additive manufacturing and covalent adaptable network. To date, he has published over 260 peer-reviewed publications, 110 patents, and 3 book chapters.

Professor dr. Chung-Hae Park



Prof Chung-Hae Park received his dual PhD degree from Seoul National University, South Korea in 2003. In 2003-2005, he worked as a senior research engineer at Technology Center LG Chemical Ltd., in South Korea, and from 2005 to 2006 as a contractual professor at the Université du Havre. He became an Assistant Professor at Université du Havre in 2006 and an associate professor at the same university in 2011. In 2013 Professor dr. Chung-Hae Park became a Full Professor at IMT Nord Europe, formerly known as Ecole des Mines de Douai and IMT Lille Douai, in France.

From 2014 until 2019 he was the group leader of ‘Composites and Hybrid Structures’ group at IMT Nord Europe, France, supervising around 25 persons, including 9 assistant/associate/full professors and 4 engineers/technicians.

In 2018 he became full professor at the first class, at IMT Nord Europe, France and he became the Deputy director in charge of innovation of the “Center for Materials & Processes” at IMT Nord Europe, France.

Main research interest and expertise include Manufacturing processes of composite materials, Numerical modelling and simulation, Natural fiber reinforced polymer composites and Multidisciplinary optimization by genetic algorithm for design for manufacture.

Herman Van Roost

Herman Van Roost studied at the University of Leuven (KUL) and holds a Civil Engineering degree in Electro Mechanics and Energy Conversion.

After 35 years of petrochemical experience with various industrial and business management functions at ExxonMobil, Petrofina and TotalEnergies, Herman Van Roost launched since 2014 TotalEnergies' activity in the circular economy for plastics as Business Development Manager Recycling.

In this position, he took up functions in the world of plastic waste and recycling as president of Plarebel and as board member of FostPlus and ValorPlast.

Since 2019 Herman joined Styrenics Circular Solutions as General Manager Feedstock and Mechanical Recycling, closing the polystyrene loop from yoghurt cup to yoghurt cup. Herman is co-author of the book 'Recycling of Plastics' published by Hanser, and is recognized for launching the slogan 'Circularity First !'.

List of Abstracts

Plenary Sessions

Circularity indicators to assess the circularity in plastic products across different industries and applications

Carla I. Martins

Institute for Polymers and Composites (IPC), University of Minho, 4800-058 Guimarães, Portugal

Abstract:

Global plastics production and consumption are continuously rising despite the general perception of plastic pollution by the society. The dilemma relies on the fact that most plastic applications brought tremendous social progress, through the increase of safety and quality of life. On the other hand, high leakage plastic applications became a problematic reality for the plastic pollution. The sustainable use of plastics and their circularity must be addressed immediately by all players involved. The scientific community has proposed a myriad of tools for this purpose, one of them being the circularity indicators. They can range widely in complexity, philosophy, calculation method, required information, and focus regarding the product life cycle. Their application can help reflecting holistically on the entire life cycle of the product to make better decisions on materials, connecting elements and assembly to promote the full recovery of the product components through currently existing waste management routes. This presentation provides an overview on the current state-of-the-art related to circularity indicators and their applicability to different industrial sectors and case studies from consumer goods, electronics, packaging, automotive and building & construction. The inherent complexity and diversity of final goods and components made with plastics across different industries and applications benefits from the inclusion of circularity indicators in early stages of decision making and product development processes for a better transition of plastics to a circular economy.

Keywords: Plastics applications, Circular Economy, Circularity indicators

From melt- to solid-stage polycondensation: how to revolutionize the design of sustainable polymers with advanced properties

Jean-Marie Raquez

Université de Mons

Additive Manufacturing of Polymer Covalent Adaptable Networks

Shaojie Sun, Jinzhi Wang, Xue Li, Hao Ouyang, Guoxia Fei, Zhanhua Wang, Hesheng Xia*

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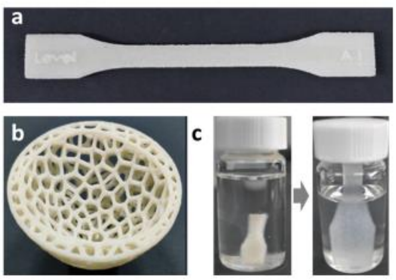
Abstract:

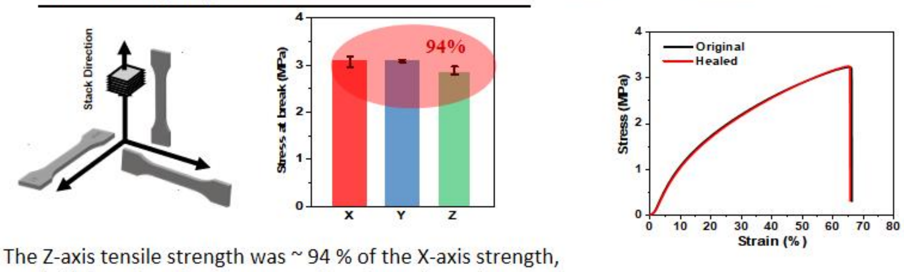
Selective laser sintering (SLS) is one of the mainstream 3D printing technologies, which use the laser energy to melt and fuse the powders and then stack layer by layer to form a printed part based on 3D model data. The major challenges for SLS technology is incomplete fusion, lower interlayer interaction and Z-direction strength, as well as the easily breaking in low-dimensional area. Herein, polymer covalent adaptable networks (CANs) were utilized to solve the challenge of SLS. Two types of novel cross-linked polymer elastomers, poly(bromophenol-urethane) (PBP-PU) and poly(pyrazole-urea-dimethylsiloxane) (PDMS-CANs), containing dynamic halogenated bisphenol carbamate bond and pyrazole urea bond were examined. The obtained PBP-PU and PDMS-CANs both exhibited excellent mechanical strength and self-healing efficiency, in addition to SLS processing ability. Small molecule model studies confirmed the dynamic reversible characteristics of dynamic bonds: chlorinated bisphenol carbamate dissociates into isocyanate and hydroxyl at 120 °C and reforms at 80 °C, pyrazole urea bond dissociates into isocyanate and pyrazolamine and reforms rapidly at 110 °C. SLS 3D printing using the self-made healable PBP-PU and PDMS-CANs powders was successfully realized. The interface interaction between the adjacent SLS layers can be significantly improved via dynamic chemical bond linking instead of traditional physical entanglement. The printed samples exhibited improved Z-direction strength, exhibiting nearly isotropic mechanical properties.

PDMS-CANs SLS 3D Printing

Printing Parameters

Parameters	PDMS
Build powder bed set temperature	75 °C
Temperature of feed cylinder	65 °C
Laser power	55 w
Outline laser power	7 w
Scan speed	7.6 m s^{-1}
Scan space	80 µm
Layer thickness	150 µm
Smart feed gain	1.2
Infrared heating lamp power ratio	0.3





The Z-axis tensile strength was ~ 94 % of the X-axis strength, much higher than that for conventional TPU (~56%).

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Hybrid flax and self-reinforced PLA (Polylactic acid) non-woven preform for lightweight biocomposites

Chung-Hae PARK

IMT Nord Europe

Abstract

Biocomposites are considered as promising alternatives to glass fiber reinforced plastics to reduce the carbon footprint. Flax fibers are among popular vegetable fibers used in many industrial sectors, owing to their high specific stiffness, i.e. the ratio of Young's modulus to density, which is equivalent to that of glass fibers. Meanwhile, the low strength of flax fibers compared with glass fibers has been one of their drawbacks. This issue of low strength becomes more crucial, if PLA (PolyLactic Acid), one of the most common bio-sourced polymers, is employed as the matrix of composites.

To enhance the ductility and strength of PLA, PLA fibers whose polymer molecules are aligned in the axial direction of fiber to provide the mechanical strength, can be incorporated inside other PLA fibers. This kind of Self-Reinforced PLA (SRPLA) filaments which have a core (i.e. PLA with highly aligned molecules and higher melting point) and sheath (i.e. PLA matrix with lower melting point) structure exhibit higher modulus and strength than pure PLA matrix.

We develop two kinds of dry nonwoven preforms. The one is composed of SRPLA fibers and the other is composed of flax fibers and SRPLA filaments. These preforms can be consolidated into a composite part by hot compression molding whose molding temperature is equivalent with that of conventional SMC (Sheet Molding Compound) compression molding (i.e. 150-155 °C). These composites have high strength as well as high modulus. In particular, on account of the low density of SRPLA filaments, the density of composites is lower than the conventional flax reinforced PLA composites and the specific strength can be increased.

Different flax/SRPLA composites with three different ratios of flax fibers to SRPLA filaments have been fabricated and their tensile and bending properties are measured. To investigate the reinforcement hybridization effect, the total sum of flax fibers and reinforcing PLA is kept constant while the relative ratios between flax and SRPLA fibers are varied. Because the ratio of reinforcing PLA to PLA matrix in the SRPLA filaments is fixed to be 50:50, however, some layers of PLA matrix film have been added to obtain composite samples, to match the same amount for the sum of flax fibers and reinforcing PLA. Because the PLA fibers are embedded in the PLA matrix filaments, the flow path is short during the molding process, and the impregnation is easy in spite of the high viscosity of PLA melt. Overall, a relatively good impregnation quality is obtained and only a small amount of voids is generated, which leads to negligible degradation of mechanical performance.

In the end, these new tertiary biocomposites show superior specific modulus and specific strength to those of SMC (Glass/Polyester) which is one of the most popular glass fiber reinforced thermoset composites. Moreover, these flax/SRPLA nonwoven preforms can easily be molded using the conventional compression molds and presses owing to the same molding temperature and pressure. Therefore, flax and SRPLA composites can be an effective alternative to glass fiber thermoset composites to reduce the carbon footprint and structural weight.

Circular Plastics : Fundamentals and Innovation Challenges

Herman Van Roost

Styrenics Circular Solutions

Abstract:

With the circular economy at everyone's attention, the plastics sector has entered a new era. Despite some successes, plastics circularity seems to be more challenging than historical achievements.

While the waste and recycling industries insist on proven solutions and pragmatic but conservative design guidelines, the development of a circular future for plastics will also depend on innovation and new technology.

But how are fundamental scientific principles interfering with circularity and with the required innovations to get there ? As always, the answer lies in thermodynamics…

Polymer Recycling

Single screw vs Twin screw extrusion of post-consumer PP packaging waste

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Abstract:

Screw extrusion is the most important polymer processing method, due to its widespread use and direct influence on productivity and product quality. Nearly all polymers undergo at least one extrusion process during their lifecycle to form pellets by resin manufacturers. This pattern is also observed in mechanical recycling where flakes must be reprocessed into granulates.

Mechanical recycling is regarded as one of the most promising method in order to enhance recycling of household packaging waste due to its economic viability and scalability. However, the influence of the additional extrusion step is not clearly understood. In this research, trends are determined between the thermomechanical history and the mechanical product properties. Moreover, a comparative analysis between single screw extrusion (SSE) and an intermeshing co-rotating twin screw extruder (TSE) is attempted in order to declare the influence on PP household waste (PCR). Furthermore, the influence of an additional drying step is investigated since PCR often contains polar components which makes the material more susceptible to moisture absorption than virgin PP. This waste stream can be categorized as a polymer blend wherein PE acts as the minor phase. Literature often prefers TSE when processing blend systems due to its beneficial mixing behavior compared to SSE.

PP with a MFI between 15 and 20 g/10min (230°C/ 2,16 kg) is processed on a Leistritz ZSE 18 (L/D = 36,5) TSE and a Dr. Collin E 30 M (L/D =25) SSE. This study observed no significant differences in mechanical properties of the PCR with respect to the used extruder type. Next, the effect of an additional drying step (100°C for at least 8h) on mechanical and rheological properties can also be neglected. Sharpy impact tests showed similar values, in the range of 6 KJ/m² for all types of processing history. However, TSE test samples showed remarkably less variation in their test results. This finding may reflect the difference in residence time distribution between the different types of extruders which is known in literature. Tensile properties show a similar trend wherein the elongation at break showed very low values (± 14%, pulling speed = 50 mm/min) according to virgin PP grades.

This study has excluded the benefit of twin screw extrusion of PCR in comparison to monoscrew extrusion. Mechanical properties didn't show significant differences due to a different thermomechanical history. Furthermore, the need of an additional drying step due to the presence of polar substituents in PCR can be neglected as both mechanical and rheological properties were similar. This outcome holds significant potential for the mechanical recycling industry, particularly in terms of comparing various process strategies.

Keywords: polypropylene; post-consumer recyclate; mechanical recycling, mechanical properties, extrusion.

Topic: Polymer Recycling
Category: Extended Abstract
Paper Number: 20401

Investigation of the silver streaks dependence on process conditions in the injection molding of post-consumer recycled polypropylene

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Abstract:

Nowadays, the use of recycled polymers in the plastic manufacturing industry is of vital importance to reduce its environmental impact, as it decreases both the quantity of underground waste and the virgin material needed to produce new components. Adopting recycled polypropylene from urban waste collection, named post-consumer polypropylene, is an issue that poses some challenges. Several problems emerge during the injection molding process, which makes it difficult to use post-consumer PP for high-value applications. In particular, the superficial appearance of the products is compromised by silver streaks, which are white stripes elongated along the flow direction. They are caused by the presence of contaminating substances inside the polymer melt, mainly residues of inks and binders, which degrade due to the high temperatures and shear stresses of injection molding, creating gas bubbles that explode on the surface. This research investigated the causes behind the creation of defects, trying to establish a link to the process parameters and to find innovative ways to address the problem.

First, we tested a new application of the gas counter-pressure technology, which consists of injecting pressurized gas from the opposite side of plastic. We used both nitrogen and air, and the results showed significant improvement in the superficial appearance of the specimens, up to complete elimination of the defects. The gas applies pressure on the flow front, thus stopping the bubbles from forming and expanding. No difference of effectiveness could be seen between nitrogen and air, so air would be the preferred choice on an economic basis. From the physics behind this process, we attempted to passively recreate a similar pressure to the flow front by employing process parameters. The idea was to compress the air above the polymer using high injection speeds. The results were positive but not as good as using active gas counter-pressure.

Regarding process parameters, from the research on passive gas counter-pressure, we noticed that the injection rate significantly affected silver streaks. Analyzing the molded specimen, which was a tensile bar, we observed that the defects were heterogeneously distributed along the length. They mainly were present at the extremities, while they decreased in the tighter section in the middle. We attributed this effect to the speed of the polymer, which doubles in the middle region. In that case bubbles probably do not have enough time to emerge to the surface. Melt temperature is also one of the main factors influencing the degradation of contaminating substances. However, using low temperatures near the melting point poses many challenges. To address this, we manufactured an experimental mold with very thin rectangular runners. These exerted high shear stress on the polymer, thus decreasing viscosity even at low temperatures. Using this mold, we could fully fill the cavity even with polypropylene at 170 °C. This could be a great starting point for further research on odor emissions of recycled materials, another concerning problem.

Defects were visible to the naked eye on the specimens, but they were also quantified using an image analysis algorithm written in Python. It is based on the difference in color between the defects, which are white, and the base material, which is grey. It calculates a standard deviation in color of the specimens. The higher it is, the more defects are present on the surface.

In summary, our effort has been on enhancing the quality of products containing recycled material, specifically poly-propylene. Different methods were taken into account, mainly focusing on process parameters and the gas counter-pressure technology. The results are promising, demonstrating the great influence of injection rate and temperature on the defect appearance. Gas counter-pressure represents a great alternative, especially with pressurized air, when changing process parameters proves to be challenging.

Keywords: injection molding; recycled polypropylene; gas counter-pressure; process parameters; silver streaks

Topic: Polymer Recycling
Category: Extended Abstract
Paper Number: 20501

Upcycling of regenerates and injection moulding through a new technological approach

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Abstract:

Lightweight fibre-reinforced plastic components contribute significantly to CO2 savings in transportation and mobility. However, sustainability challenges persist due to unresolved recycling issues. Limited research on recycling composite wastes limits their utilization in industries such as automotive, where stringent quality standards apply. The presence of a "heat history" in recycled materials complicates reprocessing, often leading fibre-reinforced composite components to end up as incineration waste. To address these challenges, innovative recycling concepts and closed-loop process technologies are essential for broader market applications [1].

The LightCycle project aims to develop injection moulding compounding (IMC) as an innovative process for closed-loop and energy-efficient processing of waste glass fibre-reinforced thermoplastic composite waste. Utilizing Austrian post-consumer polypropylene (rPP) and various chopped post-industrial thermoplastic glass fibre composites, the project maximizes material usage and reduces energy requirements through the one-step LightCycle process, leading to significant CO2 savings and the upcycling of materials into high-quality technical products. The compounded glass fibre-reinforced recycled polymer will primarily utilize unidirectional tapes and organo-sheets, composed mainly of glass fibres and polypropylene (GF/PP). Based on the initial findings of the two-step processing method, despite a significant reduction in fiber length within the samples, the tensile strength of rPP increased by up to 30% following the incorporation of 50 wt.% chopped GF/PP composites. Therefore, it is expected that via IMC, less fibre breakage and more reinforcement will be achieved. Key objectives include the development of an IMC pilot plant, formulation of methods for stabilizing and reinforcing recycled materials, creation of an inline measurement technique for monitoring fibre content and melt quality, and establishment of cause-effect relationships between process parameters, material formulations, and mechanical properties. These developments allow for robust process control with high efficiency through the utilization of a flexible modular system, complemented by an external control unit. Additionally, they enable the production of small and medium-volume components while mitigating thermomechanical stress on the polymer melt via controlled residence time. A life cycle assessment will compare the environmental footprint of the single-stage LightCycle process with the two-stage process for producing lightweight injection moulded parts from rPP. The project aims to improve efficiency and help the environment by using recycled materials and cutting CO2 emissions through eliminating granulation and material transport.

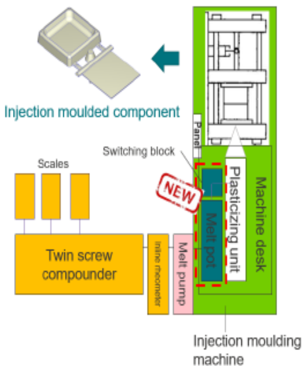

Figure 1. New LightCycle pilot plan of injection molding compounder (IMC)

Keywords: Injection moulding compounder (IMC); Post-consumer polymer; Glass fibre-reinforced thermoplastics

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Topic: Polymer Recycling
Category: Extended Abstract
Paper Number: 20601

Material Characterisation of Industrial Textile Waste

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Abstract:

Based on requirements of a circular economy to cover the complete value chain from the production of the materials to manufacturing of textiles, from the logistics of waste collection to sorting and reprocessing the material, the project “ReFibreValue” was started. The project focuses on fiber recycling and separating the smallest mixed polymer fractions and processing them into high-quality material. This involves high-quality polyamides (PA) and polyethylene terephthalate (PET).
The aim of this work is the characterization of different industrial textile waste (forming fabrics) to find out whether various processing and recycling conditions (shredding, separation) could have an influence on the thermodynamic, rheological and mechanical properties. On the other hand, the degree of purity of the waste fractions will be investigated with the aid of density measurements.
The raw materials, the new and used forming fabrics and the polymer fractions from the shredding and separation tests were examined.

Keywords: textile recycling, circular economy, fibre to fibre recycling, rheology, mechanical properties

Topic: Polymer Recycling
Category: Extended Abstract
Paper Number: 20801

Recycling the unrecyclable: Analyses of recycling opportunities in the winter sport industry

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Abstract:

According to the VSSÖ (Austrian association of sporting goods manufacturers and retailers) around 1.8 million pairs of skis and ski boots, 2.3 million pairs of ski poles and 1.4 million helmets have been sold in Austria alone, in the last five years. The resulting used sports equipment is currently treated as bulky waste at the end of its life and is therefore thermally recovered instead of being recycled. In order to improve this situation, it is necessary to establish separation, processing capacities, sales markets, product applications and process technologies for recycled materials. In relation to this problem, under the premise of the EU Green Deal, France has already introduced a levy for every product sold and it is expected that other European countries will follow suit.

The WINTRUST project, funded by the FFG and ecoplus therefore focuses on the recycling of end-of-life (EoL) post-consumer waste from winter sports hard goods, such as skis including bindings, ski boots, ski poles and ski helmets, which are mainly made from high-energy materials such as high-performance plastics or metals and are also produced in regions with lower climate protection standards in eastern Europe or Asia.

A wide range of materials are used for these winter sport goods. In cooperation with the key players in the market an evaluation of five use cases representing the main skiing equipment mentioned above is carried out. The evaluation is separated into two parts. One part includes the analysis of EoL post-consumer winter sport hard goods waste that is collected at various collection centers, its composition of materials and the options to separate the different materials from each other to be able to identify relevant material fractions. The other part is an extend interview process with the key player in the industry to collect data regarding the currently used materials, the current recycling efforts and the main issues the companies are facing when trying to implement recycling into their manufacturing facilities and processes. First results of this evaluation and the potential recycling opportunities that come with it will be presented. Following the evaluation, a plan of action to showcase the next steps with the target for industrial implementation will be displayed.

Keywords: Recycling; separation of multi-material products, sporting goods; end-of-life waste

Topic: Polymer Recycling
Category: Extended Abstract
Paper Number: 20901

Virgin/Recyclate Blends Performance Improvements for Rotomoulding

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Abstract:

Rotational Moulding or Rotomoulding (RM), is a polymer process method which is excellent for short manufacturing runs of large hollow parts. The process is a biaxial low shear processing method and can offer unique ad-vantages over various other processes. However, RM has some process drawbacks such as long cycle times, historically dependence on gas and unique material requirements. Similar to many other manufacturing methods, there is a growing desire and concern around using recycled, or waste materials within polymer products for RM. Rotomoulding hosts a significant opportunity to valorize significant amounts of end of life material given high shot weights of moulded articles, in some cases exceeding 500kg – 1000kg. Incorporation of just 10-30% at such high shot weights can use 100kgs of recycled materials, and there is scope for further adoption and higher incorporation of such materials with stronger research focus. Despite the opportunity, the nature of the low shear process and dependency on coalescence and sintering of particles during processing poses technical challenges and restrictions on progress. Especially when considering post-consumer recyclate (PCR) available from existing and well-established recycling streams sourced from high viscosity blow moulding and film grades. The purpose of this study is to investigate the enhancement of properties with the introduction of various copolymer/elastomer/rubber additions between 2.5 – 10wt% to virgin/recyclate blends (30wt% PCR). Specimens were rotationally moulded at fixed set of processing parameters before sample preparation for impact testing. The results demonstrate with such impact method improvements of impact strength of up to 140% with such incorporation. Analysis of blend rheology was also undertaken demonstrating miscible or immiscible nature of the polymer blends. The main conclusion is that this is a successful method to increase performance and therefore opening an increased number of applications for such materials in the field of Rotomoulding.

Keywords: Rotomoulding, Polymer Blends, Recyclate, Post-Consumer Recyclate, Elastomers, Copolymer

Topic: Polymer Recycling
Category: Extended Abstract
Paper Number: 21001

Polymer Processing Simulation

Coupled Matrix Monte Carlo Modeling to Support Polymeric Composite Production, Polymer Modification and Recycling

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Abstract:

A challenge to advance polymer synthesis, modification, and recycling processes is to obtain dedicated molecular control, taking into account variations at various length scales. To address this challenge, coupled matrix Monte Carlo (CMMC) modeling proves to be an interesting framework.[1-6]
In this contribution, the strength of CMMC modeling is demonstrated via case studies on (i) the production of high-impact engineering composites,[2] (ii) polymer modification via free radical induced grafting and crosslinking,[3, 4] and (iii) depolymerization processes aiming at monomer recovery.[5, 6] Special attention is given to upgrading single-phase CMMC models for batch processes to (i) multiphase models and (ii) models for (reactive) extrusion processes, which allows to predict the impact of morphological and residence time distribution variations on the make-up of individual macromolecules.

Keywords: model-based design; molecular control; morphology; compatibilizers; reactive extrusion; residence time distribution

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Topic: Polymer Processing Simulation
Category: Abstract
Paper Number: 20402

Optimization of Injection Molding using AI: Numerical Modelling and Surrogate Models based on ANN

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Abstract:

Plastic injection molding is a complex process encompassing several phases, namely plasticizing, filling, and cooling. Thus, the optimization of this process involves the need to define a high number of design variables related to the different phases of the process. Simultaneously, these variables are of different types: i) the operating conditions
including temperatures and times; ii) the mold design, including the geometry of the filling and cooling channels, number of gates and cavity; and iii) the variables that depend on the machine used. Considering the complexity of some plastic parts produced by injection molding Designing molds for injection molding is a decisive step. If adequate design principles are not followed, defects that make the parts worthless can be generated. Some common defects include short shot, flash, sink marks, warpage, weld lines and air traps. To avoid/minimize these defects various measures can be implemented, including optimizing the process parameters and using high-quality molds. In this framework, proper mold design is a critical factor in reducing some of these defects. The use of numerical modelling programs was usually pursued to obtain relevant information on the injection molding process and to enable the engineer to increase the speed of the development process and, simultaneously, allow the development of more efficient plastic parts, both concerning its functions and the use of less polymeric material. Given the large amount of data generated, which originated in the different phases of the process (plasticizing, filling, and cooling) and the high number of decision variables and objectives involved more sophisticated data analysis is required since the interdependencies between decision variables and objectives and between the objectives are complex. Also, due to the computation time required by the numerical modelling routines surrogate models to replace the original evaluation of the objective function are necessary. Therefore, the objective of this work is to develop and implement data mining techniques, and surrogate models based on Artificial Neural Networks (ANN) to deal with the data produced by a numerical modelling program of injection molding, Moldex3D, and multi-objective optimization algorithms to optimize the process. The aim is to optimize the cooling phase to design cooling channels for specific injected parts. The implementation of this methodology encompasses the following steps: i) numerical modelling results; ii) data analysis; iii) generation of surrogate models; and iv) optimization. In step i) the part to be optimized, the design variables and the objectives of optimization will be defined, and the numerical modelling results obtained. Data analysis (step ii) is used to identify correlations between the data, DVs versus DVs, DVs versus Objectives, which enabled the choice of the DVs and objectives to be used in the optimization. Then, due to the need for many runs of the modelling routine surrogate models based on ANN will be obtained in step iii) for each specific geometrical situation since the cooling channels can be made in different ways. Different methodologies will be tested and the hyperparameters of the methods used will be assessed to select the best model to use. Finally, the process will be optimized in step iv). Due to the multi-objective nature of this optimization problem, multi-objective evolutionary algorithms were adopted. The random initial population, modelled using the numerical modelling routine, will be used to perform steps i) to iii). In the next generations, the ANN models obtained are used to compute the objectives. Periodically, the ANN will be updated using new solutions evaluated by the numerical modeling routine (instead of the ANN). It was possible to obtain ANN capable of capturing the relations between the DVs and the objectives by optimizing the hyperparameters of the models used. Also, the results obtained show the relevance of the methodology proposed, allowing the selection of the relevant objectives to use and the optimization of the process, being important to note that the solutions found have physical meaning.

Keywords: injection molding, multi-objective evolutionary algorithms, surrogate models, data mining, artificial neural networks

Topic: Polymer Processing Simulation
Category: Extended Abstract
Paper Number: 20502

Numerical analysis of conformal cooling channels for small injection moulding inserts produced by additive manufacturing

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Abstract:

The progress of additive manufacturing has revolutionized the traditional process of injection moulding (IM) by enabling the creation of cooling channels that follow the geometry of the parts. Compared to conventional straight-drilled channels, conformal cooling channels (CCC) have greater potential to improve cooling efficiency, reduce warpage and decrease cycle time in the IM process, particularly for parts with thin walls and more complex geometry. As CCC are part-specific, computational analysis is fundamental to achieve optimized layouts for each application and to fully understand their influence on the most relevant IM variables. This research presents the numerical analysis of four IM inserts that were designed with different CCC for the production of small-sized reinforced parts. Computer-aided engineering simulations were performed in Moldex3D® software for all CCC design models aiming to assess the influence of the developed layouts in the IM cycle, with emphasis on the cooling phase, compared to the conventional cooling channel. This comprised the assessment of the cooling efficiency, coolant streamlines, coolant temperature, part temperature distribution and Von Mises stress. The results revealed the significant influence of the coolant path and temperature on the IM process and the properties of the parts produced. The most efficient CCC allowed to increase the cooling efficiency by more than 10%, to reduce the maximum coolant temperature by 5 ºC and to reduce the von Mises stress by 4 MPa in relation to the conventional approach. By conducting a comparative analysis of solutions, this research provides valuable insights into the selection of optimized CCC design models for small-IM processes.

Keywords: Injection moulding; Additive manufacturing; Conformal cooling channels; Computer-Aided Engineering.

Acknowledgment: This work was carried out within the framework of the “Agendas para a Inovação Empresarial” [Project nº 49, acronym “INOV.AM”), supported by the RRP - Recovery and Resilience Plan and by the European Funds NextGeneration EU. http://www.recuperarportugal.gov.pt/.

Topic: Polymer Processing Simulation
Category: Extended Abstract
Paper Number: 20602

Development of a theoretical prediction model for coefficient of friction

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Abstract:

Coefficient of friction (COF) prediction has been subject of several studies and the knowledge of this phenomenon can be a great help to predict the demoulding forces in the injection moulding process. The increase of the coefficient of friction between the two surfaces can lead to an increase in the production costs due to the increase of the demoulding force, that corresponds to the required force applied during the demoulding process. Despite the existence of some models able to predict the coefficient of friction, its application leads to inaccurate values of the coefficient of friction when applied to calculate the demoulding force. Usually are used values that are not measured or calculated in similar conditions to the injection moulding process, where need to be considered the heating of the polymer leading to the mould surface replication on the polymer surface followed by a colling process. If those processes are not considered it could lead to differences in the coefficient of friction between the two surfaces in the demoulding process. The development of prediction models for coefficient of friction considering the interface between the mould and the part surface had some issues probably due to the lack of some factor's contribution. Despite of the variety of models for coefficient of friction prediction, which in some cases are able to predict that phenomenon, it is difficult to find one that considers the replication process and other relevant factors for friction development. If certain types of polymers are used, or some factors are changed it is observed a difference in the COF behaviour and those models' application leads to inaccurate values for the coefficient of friction applied to the demoulding forces calculation. The present work aims to develop a prediction model for the coefficient of friction to be applied in similar conditions to the injection moulding process where are considered the factors that have influence in its development, including replication and test temperature, contact force, mould surface roughness as well as other factors that can contribute to its development. The contributions to the model are divided in deformation, plastic and elastic, and adhesion mechanisms and the coefficient of friction model will be applied in the existent demoulding force models.

Keywords: coefficient of friction; plastic and elastic deformation; adhesion; prediction model.

Acknowledments: This work is funded by National Funds through FCT - Portuguese Foundation for Science and Technology, References UIDB/05256/2020 and UIDP/05256/2020.

Topic: Polymer Processing Simulation
Category: Abstract
Paper Number: 20802

Micro injection molding of polypropylene parts: morphology distribution dependence on the molding conditions

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Abstract:

Injection molding is a largely diffuse manufacturing process due to the possibility to rapidly obtain parts with complex geometry and high performances. The final properties of a μ-injection molded part are mainly dependent upon the morphology developed during the process that on its turn it is affected by the thermomechanical history experienced by the polymer during the process. In semi-crystalline parts, the final morphology distribution characterized by spherulites at the core and fibrils at the surface is dependent upon the adopted molding conditions. In this work, several μ-injection molding tests were carried out on a well-characterized polypropylene. Two different cavity surface temperatures were selected, and two different flow rates for the filling stage were adopted for the μ-injection molding tests. The molded parts were characterized by microscopy to investigate the effects of molding conditions on morphology distribution. Mechanical investigations of the μ-injected molded parts were also conducted. The experimental observations allowed to determine the effects of molding conditions on the part morphology and performances.

A model that considers spherulite and fibril growth was adopted to describe the effect of molding conditions on the final morphology distribution along the part thickness. In particular, the morphology was predicted on the basis of local evolutions of both temperature and molecular stretch and of the competition between fiber and spherulite crystallization. Morphology predictions were calculated by adopting a two-step simulation. In the first step the thermo-mechanical histories were simulated by commercial software for the injection molding process, i.e. Moldflow. In the second step, temperature and flow fields predicted by Moldflow during the process were used by the model for describing fibril and spherulite formation. The model adequately predicts the main effects of the molding conditions on the final morphology distributions.

Topic: Polymer Processing Simulation
Category: Extended Abstract
Paper Number: 20902

New approach to design conformal cooling channels (CCC) through 2D simulation

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Abstract:

The advance of the additive manufacture of metal parts allows the mold-makers includes conformal cooling channels (CCC) inside the mold`s cavities to enhance the thermal exchange during the injection molding process. The design of such cooling channels faces the features: achieve a reasonable thermal exchange; keeping the mechanical properties to support the requirements for molding process, besides to be possible to manufacture by additive manufacturing (usually by selective laser melting technique – SLM). Thereby, the design of the CCC is usually an arduous task, what the engineer has to deal with different possibilities of CCC designs and make diverse 3D CAE simulations - CUSTO COMPUTACIONAL. Considering this blackguard, the current work proposes a simple 2D analysis as a first step for starting a CCC design. It furnishes a reasonable direction for the CCC designers, instead of expending much time on 3D simulations. This proposed analyze consider the diameter of CCC, pitch surface and pitch channel. A sketch is presented at **Fig. 1**.

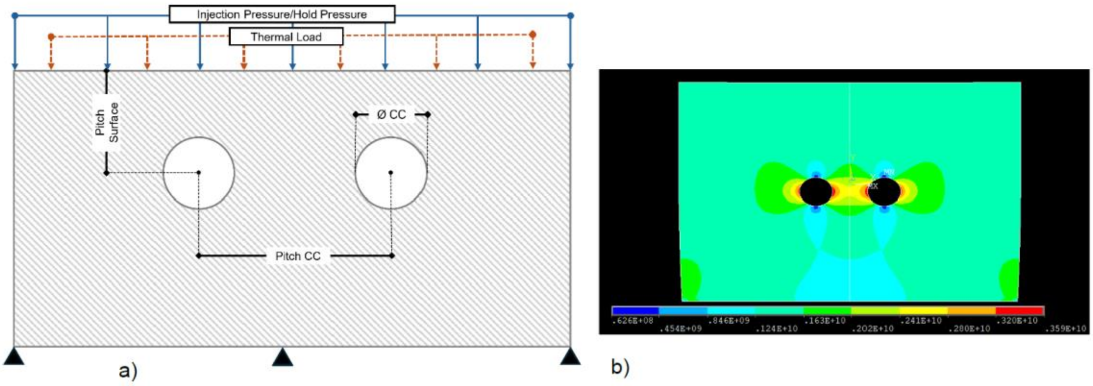

Figure 1 - a) Problem 2D diagram b) Partial results data of Von Mises stress

A solution was developed by an analytic and numerical model using finite element method (FEM), considering state of plane stress. Both results were evaluated and exhibit satisfactory convergence. After that, using a real injection mold, the proposed 2D method was applied and it successfully found an optimized direction to CCC design considering thermal and mechanical behavior, instead of doing several 3D CAE simulations from the scratch. Thus, the method proved to be very useful in saving time on the CCC design.

Keywords: conformal cooling channels; additive manufacture; injection molding; CAE simulation

Topic: Polymer Processing Simulation
Category: Abstract
Paper Number: 21002

Developments in Polymer Processing

Connecting experimental and modelling approach for grafting of poly(lactic acid) during reactive extrusion

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Abstract:

Plastics are widely used in a variety of applications ranging from packaging to high-end use-cases, e.g. wind turbines and electronics, due to their mechanical integrity and lightweight nature. In recent decades, sustainability challenges regarding the depletion of resource material and pollution due to landfill are of major concern [1], [2]. Biopolymers, such as poly(lactic acid) (PLA) offer a solution to these challenges as these are derived from renewable sources and can be biodegradable in natural settings [2]. PLA is of great interest as it exhibits similar properties to commodity plastics, such as polystyrene (PS) and polyethylene terephthalate (PET), while also providing good barrier properties. Nevertheless, (unmodified) PLA has shortcomings in terms of mechanical strength, melt strength, thermal stability and crystallization speed [1], [2], [3]. Different attempts to improve PLA's properties are investigated, including blending, fiber reinforcement and chemical modification of the material [3], [4], [5].
Chemical modification of PLA is done via grafting and crosslinking using a radical initiator, e.g. dicumyl peroxide (DCP). The most economical viable method to use, is a reactive extrusion process (REX). During this process, in the melt, hydrogen is abstracted from the PLA backbone due to the decomposition of DCP, resulting in the formation of mid-chain radicals (MCRs). These MCRs can recombine, leading to a branched and eventually, crosslinked structure of PLA, increasing the (average) chain length. On the other hand, chain (β-)scission is another undesired reaction occurring, leading a decrease in (average) chain length. The recombination of MCRs can be promoted using crosslinking agents (CAs), e.g. triallyl isocyanurate (TAIC) [6].
In the present work, varying quantities of DCP are used to naturally, without the addition of CAs, crosslink PLA via a REX process. To quantify the success of this chemical modification experimental characterization is combined with coupled matrix-based Monte Carlo (CMMC) simulations. Experimental analyses, such as Soxhlet extractions, are employed to examine the soluble and gel fractions of the resulting product. Further insight into the process is obtained by altering parameters, such as the residence time distribution (RTD) within the extruder. The goal of the current study is to combine both the experimental and modeling approach to bridge the molecular and macroscopic properties, enabling a better understanding and the possibility to further fine-tune the process.

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Keywords: reactive extrusion; PLA; crosslinked polymers; coupled matrix-based Monte Carlo simulation, chemical modification

Topic: Developments in Polymer Processing
Category: Extended Abstract
Paper Number: 21301

Developing Recycling Strategies for Expanded Polystyrene Packaging

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Abstract:

The European Green Deal aims to decrease single-use plastics, therefore strategies to reduce the amount of products like expanded polystyrene (EPS)-based materials are of extreme interest. Current recycling strategies for EPS rely mainly on mechanical routes, where the material is grounded or shredded and then molten and molded into new products. Nevertheless, so, the existing strategies allow only a 15-20% reintroduction rate in the manufacturing process.

This work aimed to develop a novel recycling strategy for EPS-based products applied to the reality of the Portuguese manufacturer Petibol. In this strategy, single-use EPS-based packaging produced by the company was mechanically disintegrated back into spheres and reintroduced into the manufacturing process at high percentages (40%-100% recycled material) without requiring the melting step. When 100% of recycled EPS spheres were used, it was possible to thermomold the material, but a strong shrinkage of the molded piece was verified during cooling. To avoid this, an epoxy-based bonding agent was introduced to the thermomolding process at specific ratios (5-40 wt%) to the recycled EPS spheres. With the use of the bonding agent, the recycled material pieces showed an improvement in the visual aspect (Figure 1), not only by keeping similar size and form but also by presenting a lower superficial roughness. The mechanical properties of pieces containing only recycled material and bonding agent were nearly equivalent to the pristine pieces, with a marginal difference in compression strength of ca. 20 kPa. Therefore, despite some visual flaws, the use of an epoxy-based bonding agent during the thermomolding of mechanically disintegrated EPS-based packaging revealed to be a promising approach to enable EPS recyclability.

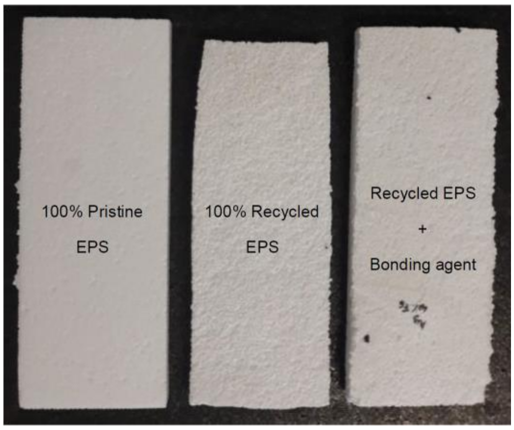

Figure 1- Digital images of molded samples of 100% pristine EPS, 100% recycled EPS, and a mixture of recycled EPS and bonding agent.

Acknowledgement: The present study was developed in the scope of the Project “Agenda ILLIANCE” [C644919832-00000035 | Project nº 46], financed by PRR – Plano de Recuperação e Resiliência under the Next Generation EU from the European Union and of the project CICECO-Aveiro Institute of Materials, UIDB/50011/2020, UIDP/50011/2020 & LA/P/0006/2020, financed by national funds through the FCT/MEC (PIDDAC). FCT is also thanked for the Individual Call to Scientific Employment Stimulus (IG, https://doi.org/10.54499/CEECIND/00430/2017/CP1459/CT0032).

Keywords: Expanded Polystyrene; Reprocessing; Bonding agent.

Topic: Developments in Polymer Processing
Category: Abstract
Paper Number: 21401

Correlation of Stereo DIC and Thermographic Imaging to Monitor Vacuum-Assisted Thermoforming of Thermoplastic Sheets

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Abstract:

This experimental study focuses on the dynamic behaviour of a 3mm thick ABS sheet during vacuum-assisted thermoforming, concentrating on the forming stage of the process. In this stage, the heated sheet undergoes fast and large deformations. The sheet is stretched by the mould and the applied vacuum. The objective of the present study is to elucidate the complex behaviour of the sheet during these large rapid deformations. Due to the nonhomogeneous IR heating, convective heat transfer to the surrounding air and conductive heat transfer to the mould, the deformation of the sheet is not isothermal. Utilizing Digital Image Correlation (DIC) in tandem with thermal imaging, the research accurately maps the strain field and deformation rates in relation to real-time temperature variation on the material. The used mould in this study is made out of cast aluminium and consists of a 40x40cm square base with a 250mm diameter positive semi-sphere in the centre. The proposed experimental setup is able to track the occurring displacement and temperature fields. Postprocessing of the data reveals the strain, strain rate and thickness evolution of the sheet. The experiment is validated by comparing thickness measurements derived from DIC's principal strain directions to ultrasonic thickness gauge readings. This knowledge not only broadens the understanding of the thermo-mechanical material behaviour but also aids in optimizing process parameters for improved thickness uniformity in thermoformed products.

Keywords: Digital Image Correlation; Vacuum forming; Thermal imaging, large strain deformation, thermoplastic sheet

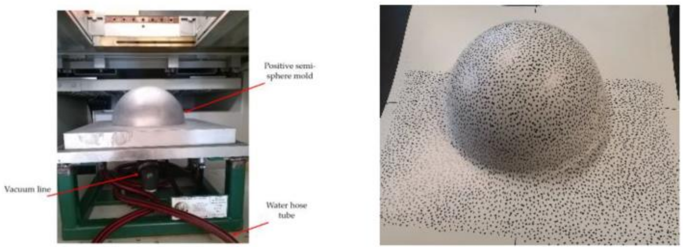

Figure 1: Semi sphere, D250mm, thermoforming mould (left), thermoformed product with DIC spackle pattern (right)

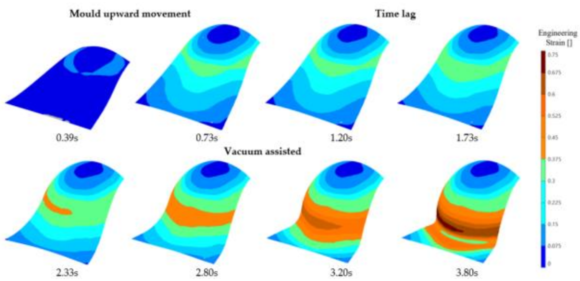

Figure 2: Maximum principal engineering strain of the ABS sheet, recorded at different forming steps through DIC correlation and post-processing

Topic: Trends in Product Development
Category: Extended Abstract
Paper Number: 21501

Development of a production methodology based on rheological parameters for robotic extrusion additive manufacturing of thermoplastic materials

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Abstract:

The rapid expansion of additive manufacturing (AM) into large-scale applications demands precise control over process parameters for optimal performance. Some research has been conducted in recent years aiming the evaluation of molten polymer flow under the minimum set of dimensionless parameters; nonetheless, it is mainly centred on conventional material extrusion processes. This study presents a novel characterization methodology tailored for optimizing such AM processes, particularly, focusing on the robotic extrusion of polymeric systems. Most of the challenges arising from this technology are due to rheological effects of the material that were not anticipated, wherefrom optimization is overly dependent on trial-and-error. Moreover, understanding the correlations between process parameters, rheological material properties, and product geometry is crucial. Through a systematic approach, key process parameters such as extrusion temperature, extrusion flow rate and die pressure drop, as well as single-screw extruder geometric factors were studied to enhance print quality, layer uniformity, and production efficiency. Based on the experimental determination of the extrusion flow rate versus pressure drop for a given material, the linear extrusion velocity could be calculated analytically, yielding a die characteristic curve for a fixed processing temperature and nozzle diameter. Comparative experimental results were utilized to validate capillary rheometry measurements and identify optimal parameter settings that strike a balance between build speed and part quality. This research contributes to the advancement of large-scale additive manufacturing by providing a comprehensive framework for process optimization, paving the way for efficient and reliable production of polymer-based components.

Keywords: Robotic extrusion additive manufacturing; rheological parameters; thermoplastic materials; large parts; printing guidelines

Acknowledgment: This work was carried out within the framework of the “Agendas para a Inovação Empresarial” [Project nº 49, acronym “INOV.AM”), supported by the RRP - Recovery and Resilience Plan and by the European Funds NextGeneration EU. http://www.recuperarportugal.gov.pt/.

Topic: Developments in Polymer Processing
Category: Extended Abstract
Paper Number: 21801

Insights into kinetics and mechanism of polymerization reactions via inline Raman spectroscopy

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Abstract:

Characterizing polymerization reactions is pivotal when scaling up chemistries from lab to plant. The ability to understand the kinetics and mechanistic aspects under reaction conditions is crucial to translate a lab recipe into scale. Traditional methodologies, such as sampling and ACOMP (automatic continuous online monitoring of polymerization) are widely applied and provide insights along other methods, such as gel permeation chromatography, calorimetry etc. Herein, we present inline Raman spectroscopy for characterizing true and representative reaction kinetics and mechanistic aspects. Raman spectroscopy has been established for characterization and is commonly used as an offline tool, herein the present the possibility to probe polymerization reactions via Ballprobe based MarqMetrix All-in-One Spectrometer. The journey starts in laboratory where real time reaction monitoring is applied to build the fundamental understanding. As Raman is sensitive to the backbone of the molecule, the reaction progression can be monitored via fingerprint. Orthogonal methods are applied to translate the qualitative picture into quantitative measures for characterization. This method can now be accessed for design of experiments studies for process optimization and creating a robust recipe for scale.

Keywords: Raman; kinetics; scale-up; inline monitoring; real time reaction insights (List three to six keywords specific to the research topic).

Topic: Developments in Polymer Processing
Category: Abstract
Paper Number: 21901

Long chopped natural fiber biocomposites: Micro-Processing and characterization

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Abstract:

Long chopped fiber-reinforced thermoplastics (LFT), having the advantage of structural properties such as good balance of mechanical properties and durability with relatively low cost, are widely used in automotive and other transportation sectors to replace metal parts. LFT materials contain longer fibers than short fiber composites that provide longer residual fiber length in the injection molded features with higher structural properties such as higher specific stiffness and toughness. Glass and carbon fiber are predominantly used as reinforcement materials in LFT composites and there are numerous recent studies about natural fiber reinforced polymer matrix composites mainly driven by recyclability and sustainability purposes.

In this study, biopolymer blends of PLA, PHA and NCC (Nanocrystalline Cellulose) were prepared using a micro compounder. In the next step, sisal fiber was successfully coated with the biopolymer blend to produce filaments. Then, these filaments were cut into pellets of 1 cm length and were melt mixed in a micro compounder and subsequently molded into test specimens using a lab scale injection molding machine. The parameters such as effect of sisal fiber reinforcement, biopolymer composition (PLA and PHA blend) and incorporation of NCC (Nanocrystalline Cellulose) in the biopolymer blend were investigated. The mechanical properties were investigated with findings from tensile and impact test. Thermal properties were evaluated by using TGA and DSC measurements. This study provides a good starting point for discussion and further research on long chopped natural fiber reinforced biopolymer composites.

Acknowledgement:

The authors would like to thank Zoey Gelissen for her valuable support in compounding studies during her internship.

Keywords: Long fiber thermoplastics; biocomposites; composites; biopolymers; micro-compounding.

Topic: Developments in Polymer Processing
Category: Abstract
Paper Number: 22001

Morphology, conformation, and thermal-mechanical properties development in solid-state processed Polymer materials.

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Abstract:

Solid phase orientation by die drawing is a highly effective process for enhancing the physical properties of many polymers. Optimizing the die drawing process involves controlling variables such as draw temperature, draw forces, draw speed, and die geometries, which influence the strain rate field in the deformation zone. Understanding the mechanical, thermal, and molecular characteristics of the polymer is essential for this optimization. Evaluations of oriented polymers include WAXS-SAXS, FT-IR, DMA, DSC analysis and assessments of mechanical properties. Studies on polyolefins, TPVs, and PET illustrate the data needed to interpret and optimize die drawing behaviour. Enhanced physical properties, such as Young's modulus, are consistently observed and were found to be strictly dependent on solid state process parameters, which in turn define the degree of molecular orientation.
Spectroscopy studies on PET have demonstrated strain-induced conformational changes, similar to those occurring upon cold crystallisation, but still underpinning the important role of the oriented amorphous matrix in the mechanical properties' development. Additionally, research on PET/PMMA blends reveals insights into the thermal expansion coefficients of these materials, drawing onto morphological rearrangement driven by the solid-state process. Exposing the blends to repeated heating and cooling cycles, it was found that downward jumps in temperature produce small transient increases in the total stress, leaving it effectively unchanged – this provides valuable information for applications requiring specific thermal stability and dimensional precision.

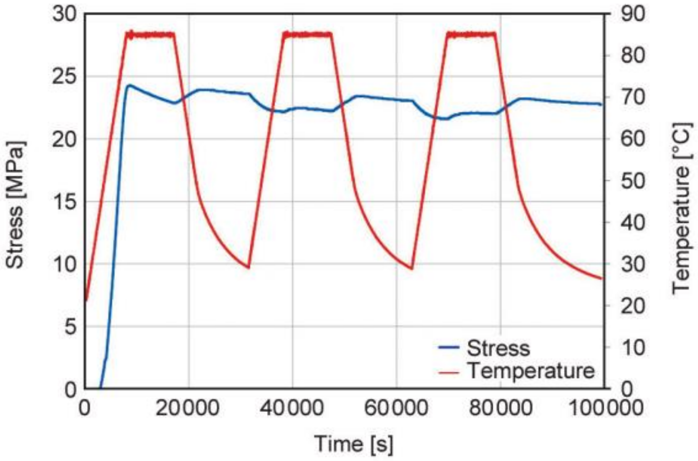

Figure 1: Shrinkage stress for PET/PMMA blend with repeated cooling and heating.

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Keywords: Mechanical properties; Molecular orientation; Die-drawing, Thermal-mechanical stability.

Topic: Developments in Polymer Processing
Category: Abstract
Paper Number: 22101

Sustainable use of polymers

Thermoforming of biocomposites with agrifood wastes and essential oils

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Abstract:

In the frame of the circular economy, the use of agrifood waste from different industries reduce the use of other raw materials and, simultaneously, contributes to the valorization of waste. One of the most feasible routes to achieve this goal is developing biocomposite materials with biopolymers as polymer matrix. Furthermore, and since some agrifood waste contains odor and since smell is the least stimulated senses, there is an opportunity to develop new materials that seek to enhance the odor of waste and its identification by consumers. In this study, were developed biocomposites using the biopolymer Inzea F38, supplied by Nurrel, with orange peels and spent coffee grounds, together with essential oils, in order to intensify the released aroma. Were carried out tests, in order to select the amount of wastes and essential oil to be used, reaching formulations with 80% biopolymer and 20% of a mixture between filler and essential oil. Ten individuals carried out smell tests during 8 weeks to evaluate the release of the aroma. Other characterization tests, including thermal analyses, DSC and TGA, rheological, MFI, and mechanical tensile tests, were done to evaluate the addition of wastes and the essential oils. The results show a plasticizing effect due to the addition of the essential. Were produced sheets by compression molding and thermoformed parts with different draw ratios. It was concluded that it is possible to thermoform parts with a draw ratio of at least 2 and, given the plasticizing effect, the addition of essential oils allows lower thermoforming temperatures.

Keywords: Agrifood waste, biocomposites, orange peels, spent coffee grounds, essential oils.

Topic: Sustainable use of Polymers
Category: Extended Abstract
Paper Number: 21302

Enabling Closed Loop Plastics Processing

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Abstract:

One of the main technical obstacles to closed loop plastic recycling is the degradation it undergoes throughout its life cycle. This can be caused when the material is subjected to thermomechanical processing conditions or external stimuli such as radiation, temperature or aggressive chemical environments, and is reflected in the rheological, thermal and mechanical properties, among others. This affects not only the processability of the materials, but also the performance of their products, leading to the rejection of recycled raw materials, either because of uncertainty about their behavior or because of the limited quality that can be achieved in the end products. Additives can be used to restore the properties of plastics. However, their use should be as efficient as possible and only when necessary. This is because they entail additional costs, and it is necessary to balance the environmental benefits associated with their use with the negative impacts potentially associated with their life cycle. In this study, poly(lactic acid) (PLA) was (re)processed for up to three cycles, through extrusion and fused filament fabrication (FFF), starting with virgin pellets at the first cycle. To reprocess the plastic, printed parts were ground in a granulator. Before the last cycle prior to testing, 1,3-bis(4,5-dihydro-2-oxazolyl)benzene (PBO), a chain extender understudied in PLA, was mixed with the plastic in an internal mixer at 0.5, 1.0, and 2.0 wt% concentrations. Both the effects of reprocessing and those of PBO's concentration were investigated. Fourier-transform infrared (FTIR) spectroscopy did not show detectable differences between formulations or in degraded material. Near infrared (NIR) spectroscopy revealed changes corresponding to degradation but did not reflect additive content. In contrast, differential scanning calorimetry (DSC), double capillary rheology, and tensile tests revealed changes in properties for the reprocessed PLA and their recovery or even improvement relative to the virgin polymer's. Thus, this work shows a pathway for recycling PLA multiple times without sacrificing its performance, further closing the loop on PLA recycling.

Keywords: Closed-loop manufacturing; additive manufacturing; polymer degradation; quality assessment; chain extender.

Topic: Sustainable use of Polymers
Category: Abstract
Paper Number: 21402

Development of an underwater pelletizer for obtaining extruded recycled expanded polystyrene beads

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Abstract:

expanded polystyrene (EPS) molding industry usually relies on blowing agent-containing microgranules as raw materials. These microgranules are obtained through suspension polymerization in the presence of pentane and are preferred due to their convenience of storage and transportation. However, the use of expandable polystyrene (PS) beads as raw materials poses challenges to the integration of recycled content during the molding process. In fact, as EPS regrind is mainly composed of damaged beads which display a marginal blowing agent content in their composition, the acceptable amount of secondary EPS in the production of new parts has been limited to approximately 20% by weight. Therefore, there is a need to develop new processing strategies that allow to further enhance the recycled content in the scope of EPS molding industry.
In this study, a new processing strategy based on the combination of blowing agent-assisted extrusion and underwater pelletizing was studied. Herein, a laboratory-scale twin-screw extruder (Process 11, Thermo Fisher Scientific) was adapted, and a custom-made underwater pelletizer was developed for producing low-density PS foam beads with uniform geometry. The process validation consisted of evaluating the influence of recycled EPS on the extrusion of pentane-containing PS beads, with the aid of a chemical blowing agent (CBA) based on sodium bicarbonate and citric acid, on apparent density, expansion ratio, and bead geometry. Moreover, the mechanical performance and morphological parameters of the foam beads and consolidated parts were determined and compared to both virgin EPS parts and parts containing increasing contents of EPS regrind without prior treatment. By allowing the production of recycled PS beads with uniform geometry and upgraded properties, this processing strategy promises to facilitate the valorization of EPS molding industry's by-products and to pave the way to a closed-loop recycling methodology for this category of materials.

Keywords: circular economy; closed-loop recycling; chemical blowing agent; foam extrusion.

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Topic: Sustainable use of Polymers
Category: Abstract
Paper Number: 21502

Polymer Rheology

Experimental viscosity measurements on gas-laden polymer melts

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Abstract:

Reducing the amount of required material to create a product is one way to reduce its footprint, cost, and weight. In polymer processing applications, such as injection molding or extrusion, this can be achieved by adding a chemical blowing agent to the polymer. This blowing agent's purpose is to infuse a gas, typically CO2 or N2, into the melt and create a cellular structure in the material during processing. This results in a foamed material that is lower in weight than the solid alternative, and often possesses improved mechanical properties per unit of weight, especially in the case of injection molding. It is found that adding blowing agent, even in lower quantities, reduces the viscosity of the melt. Lower viscosity is advantageous in processing, as it lowers stress under similar strain. In injection molding, this results for example in reduction of necessary injection and holding pressures.
Determining the exact impact of the blowing agent on the viscosity of the melt is however not straightforward. The gas needs to be homogeneously dissolved into the melt, as is the case when melting the combination of polymer pellets and blowing agent in an extruder or injection unit. Furthermore, the gas will start nucleating below a certain pressure. This reaction will cause the melt to foam, often rendering the sample useless, as in **Fig. 1**.

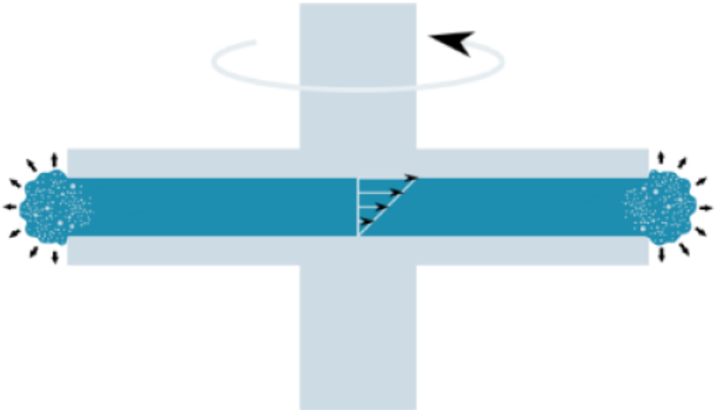

Figure 1: Material foaming up in a rotational rheometer will invalidate the assumptions regarding shear deformation

Adapted setups have been presented before, but these are mostly unfit for measuring shear rates as they occur in injection molding. This study focuses on alternative ways to characterize the viscosity of such gas-laden polymer melts through the use of different experimental setups. An extruder fed capillary rheometer with controlled exit pressure will be compared with slit die extrusion measurements and spiral die injection molding measurements. The latter options should provide a simple alternative to quantify the viscosity impact in an industrial environment, where specialized lab equipment might not be available.

Keywords: foamed injection molding; chemical blowing agent; polymer rheology.

Topic: Polymer Rheology
Category: Extended Abstract
Paper Number: 21802

Advancing Mechanical Performance of 3D Printed Lattice Structures via Rheological Optimization: A Doehlert Experimental Design Study

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Abstract:

Lattice structures are composed of repeated unit cells and are known for their unique mechanical properties, making them ideal for lightweight and high-performance applications. Utilizing additive manufacturing techniques such as Fused Filament Fabrication (FFF), these lattice metamaterials can be efficiently produced. A critical aspect of their fabrication is the control of rheological parameters during the extrusion process to achieve the desired mechanical properties.
This study explores the impact of these rheological properties, specifically viscosity and shear, on the mechanical performance of lattice structures. We employed a Doehlert experimental design in conjunction with Response Surface Methodology (RSM) to systematically adjust these parameters during the printing process, aiming to optimize the com-pressive strength and stiffness of the structures. The experimental framework was applied to configurations of Poly (lactic acid) (PLA), known for its rigidity and environmental benefits, and Thermoplastic Polyurethane (TPU), valued for its high flexibility. This approach enables the precise tuning of failure stress and deformation characteristics.
Our findings provide significant insights into how rheological parameters influence the mechanical properties of 3D-printed lattice structures. The optimized settings derived from the Doehlert experimental design offer a systematic method to enhance the performance of these structures across various engineering applications.

Keywords: Lattice structures; Doehlert Design; response surface methodology; Mechanical Properties; 3D Printing Optimization; Rheology

Topic: Polymer Rheology
Category: Extended Abstract
Paper Number: 21902

Comparative study on PA12 and PA11 degradation for HP Multi Jet Fusion process

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Abstract

Additive Manufacturing (AM) indicate the production of customized parts in polymer, metal or ceramic material by mean of a layer by layer build up. Typically, 25 kg of polymer powder is used for one print. However, the produced part will contain only 20% of all the material leaving 20 kg of post-industrial polymer waste[1]. It is of great environmental and economical concern the improvement of the process circularity through understanding of the polymeric powder aging.

PA powder is the most commonly adopted for power bed techniques and, among them, PA12 and PA11 are the most popular for MJF[2]. An increased interest on PA11 has arisen in the later years due to its bio-based origin[3]. However, PA11 powder undergoes severe discoloration during printing, which has been linked mainly to thermo-oxidative degradation[4]. A solution was proposed in this study regarding the possibility to switch to an inert atmosphere. This will allow multiple recycling cycle of the powder. We compared vacuum-aged and air-aged samples, which was the key to a better understanding on the aging process and the effect of this last. Color analysis was performed on PA11 and PA12 powder, both aged in vacuum and in presence of air. This analysis was coupled with molecular analysis, through FTIR, which proved the formation of chromophore groups in the air aged powder. Moreover, to better understand the mechanism, GPC analysis was performed, showing that the chain scission mechanism happens simultaneously with other types of chain recombination. Finally The effect on the flow properties of the melt were investigated through rheological analysis.

Keywords: Polyamide 12, Polyamide 11, Multi jet fusion, 3D printing, Thermal-oxidative degradation, Additive manufacturing, Recycling.

Acknowledgment: This work is funded by Vlaio: GreenAM project.

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Topic: Additive Manufacturing
Category: Extended Abstract
Paper Number: 22002

Additive manufacturing sensor design for energy harvest and action recognition

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Abstract:

Self-powered flexible devices with multiple sensing abilities have attracted great attention due to their broad application in the Internet of Things (IoT). Various methods have been proposed to enhance the cheaper-fast or electric performance of flexible devices; however, it remains challenging to realize the display and accurate recognition of motion trajectories for intelligent control. Here we present a fully self-powered 3D printable-triboelectric bimodal sensor based on ultra-long micro-nanostructured silver nano-wires (AgNWs) and thermoplastic elastomer, which can patterned-display the force trajectories. The deformable silver nanowires used as stretchable electrodes make the stress transfer stable through the overall device to achieve outstanding self-powered properties. Moreover, the roughness of the surface is enhanced by treatment with sandpaper which endows the resulting device with significantly improved triboelectric performances (voltage increases from 5 to 16 V). We observed that the 3D printing-obtained composite exhibited exceptional self-powered performances and sensing properties, enabling the development of a highly reliable machine learning-based motion recognition. This advancement offers a promising approach for future IoT-era devices focused on advanced action interaction and smart wearable electronics.

Keywords: Sensor design, AgNWs, Additive manufacturing, TENG

Topic: Polymer Rheology
Category: Extended Abstract
Paper Number: 22102

Additive Manufacturing

Mechanical Recycling and stabilization of ABS from post-consumer Electric and Electrical Equipment (EEE) waste for filament production for FFF applications.

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Abstract:

In this study, post-consumer ABS waste from refrigerator parts has been investigated regarding its restabilization and upcycling via additive incorporation during mechanical recycling process in view of filament production for FFF applications. The ABS waste used for this study had previously been sorted by density and electrostatic separation. As a next step, the material was further purified by melt filtration with a screen of 140 μm mesh size. Following, the material was reprocessed in a single screw extruder for 5 cycles for the evaluation of thermo-oxidative degradation. Rheological and mechanical properties throughout the reprocessing cycles were evaluated via Melt Flow Rate, Parallel Plate Rheology, Tensile and Impact testing. In the next part of the study, the ABS waste was compounded in a twin-screw extruder with two different antioxidant additive blends. The com-pounded materials were reprocessed respectively in a single-screw extruder for 5 cycles. Results from rheology and mechanical tests were compared with the respective results from the initial neat grade for the determination of the optimum additive formulation. Finally, the material was used to produce filament for 3D printing applications.

Keywords: Acrylonitrile Butadiene Styrene; mechanical recycling; antioxidants; EEE waste; 3D printing filament

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Topic: Additive Manufacturing
Category: Abstract
Paper Number: 30301

A preliminary study on the flow-induced crystallization phenomenon in 3D printing of Polyvinylidene fluoride

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Abstract:

Fused Filament Fabrication (FFF) is a widely used additive manufacturing (AM) technique, renowned for its versatility, affordability, and ease of use. It involves the layer-by-layer deposition of extruded thermoplastic filaments to build three-dimensional objects. In the context of high-performance semi-crystalline polymers, FFF, which is also known as 3D printing, presents both opportunities and challenges due to the unique properties of these materials. A notable opportunity lies in the ability to orient and align polymer chains. During the 3D printing process, both the shear flow within the nozzle and the velocity gradients induced by deposition can significantly deform the polymer microstructure. This deformation, termed flow-induced crystallization (FIC), mitigates kinetic barriers to crystallization and directs the resultant morphology. This phenomenon of enhanced oriented crystallization could be crucial for the production of piezoelectric devices of Polyvinylidene fluoride (PVDF). PVDF is a thermoplastic semi-crystalline polymer distinguished by its polymorphism, with multiple crystalline phases that significantly impact its properties and applications. The piezoelectric effect of PVDF is closely linked to the β-phase content, morphology, and alignment, all of which are influenced by processing conditions. This study aims to investigate the potential and limitations of flow-induced crystallization for producing PVDF specimens with high β-phase content.
A Design of Experiments (DoE) methodology was employed to examine the effects of two factors, printing speed and extrusion temperature, on various response variables. These response variables were identified through comprehensive characterization analyses. Post-printing, measurements such as the total crystallinity and the melting temperature were obtained via differential scanning calorimetry (DSC), while the β-phase percentage was assessed using Fourier Transform Infrared Spectroscopy (FTIR).
ANOVA analysis of the DSC results indicated that extrusion temperature is the critical parameter, positively influencing total crystallinity. Conversely, the melting temperature was found to increase as the extrusion temperature decreased. Furthermore, statistical analysis of the FTIR results reinforced the significance of extrusion temperature on the crystallization phenomenon, revealing that the β-phase content increased with decreasing extrusion temperature. From these findings, it can be inferred that low extrusion temperatures could decrease system entropy due to the alignment of polymer chains induced by the material flow. Additionally, a combination of increased extrusion temperature and low printing speed promotes the nucleation and growth of crystals. However, this condition diminishes the likelihood of achieving a microstructure characterized by a high β-phase percentage.

Keywords: FFF; 3D printing, PVDF; Flow-induced crystallization; b-phase

Topic: Additive Manufacturing
Category: Extended Abstract
Paper Number: 30401

Characterization and computational modeling of 3D printed structure via fused filament fabrication

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Abstract:

Additive Manufacturing (AM) have been showing significant advantages on raw materials saving, fast operation, and customized geometries for complex structure components. Adding nanomaterials such as carbon nanotubes to host matrices via AM technologies has the potential to enable greater capabilities in nanocomposites production. The aim of the present work was to study physical properties including mechanical, thermal and morphological properties of multiwall carbon nanotube reinforced polylactic acid composites (MWCNT/PLA) manufactured by fused filament fabrication with varying process conditions and CNT concentration. The properties of the home-made MWCNT/PLA filaments were first evaluated by means of morphological, thermal and mechanical investigations. Then, the effects of CNT concentration (0.5 wt.%, 0.75 wt.%, and 1.0 wt.%) as well as infill density (60 %, 80 %, and 100 %) on mechanical properties including tensile behaviors, flexural behaviors and interfacial shear performance of 3D printed composites were carefully analyzed. The deformation processes and failure mechanisms of laminated composites were analyzed in association with morphological evolution. Based on the experimental investigation, a constitutive material model of 3D printed parts via fused deposition modeling was developed in the present study. Additive manufacturing of a part results in a complex microstructure which depends on the process parameters. Anisotropy is introduced into the material properties. The mechanical behavior of the printed parts is governed by the constitutive behavior of the material. Therefore, the stiffness matrix of the material of the final printed part needs to be estimated for accurately capturing their behavior. The constitutive material modeling of the printed parts using numerical homogenization procedure is emphasized in this work. The mesostructure of layers of the printed parts was considered for finite element modeling of the representative volume element (RVE), and to determine their elastic moduli. The results showed that, with one more heating process, PLA-mix (went through mixing, extruding and printing) showed both lower rigidity and ductility than PLA-control (went through extruding and printing). Moreover, compared to PLA-mix, CNT/PLA composites always presented higher young's modulus and tensile strength, and similar elongation at break. As for flexural behaviors, the introduction of CNT increases flexural modulus and elongation at failure while decrease the energy absorption capability of CNT/PLA composites. Finally, the FEM model presented in this work allows to predict 3D printed parts using some practical assumptions, but keeping accurate results. The computational models provided more insights on the final properties of 3D printed parts for different materials. In summary, this research work represents an important step towards enabling the effective design and analysis of 3D printed structures using both experimental investigation and computational methodology.

Keywords: Additive manufacturing; Mechanical properties; Carbon nanotube; Mesostructure; Computational modelling

Topic: Additive Manufacturing
Category: Abstract
Paper Number: 30501

L-PBF of aluminum: mass reduction and hybrid manufacturing of an aeronautic part

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Abstract:

Laser Powder Bed Fusion (L-PBF) refers to a category of additive manufacturing processes that use a laser source to sinter powder particles that are deposited successively, layer by layer, on a build platform in a controlled environment (Gibson et al., 2010; Yuan et al., 2019). Depending on the technological variant, such as Selective Laser Sintering (SLS) or Direct Metal Laser Sintering (DMLS), L-PBF processes enable the laser sintering of various materials, in-cluding polymers and metals (Gibson et al., 2010; Dev Singh et al., 2021). The ability of these processes to meet the requirements of a wide range of applications has boosted the market for L-PBF technologies, which is estimated to show an annual growth rate of around 30% between 2018 and 2024 (Markets, 2019).
In fact, the sintering of metallic materials is increasingly becoming an alternative to metal casting, even though they have some porosity, roughness and low dimensional accuracy. Even so, the geometric freedom that additive manu-facturing allows, combined with good mechanical properties, makes metal sintering technologies a viable and advan-tageous alternative for technical applications with some complexity, such as the automotive and aeronautical indus-tries. For this reason, the characterization of their physical, mechanical and thermal properties is crucial for a better understanding of the technology.
Another possibility using L-PBF is the hybrid manufacturing which combines conventional and additive technologies, making it possible to produce functional parts with complex geometries that are generally difficult to produce using conventional methods. The main objectives of hybrid manufacturing are to reduce production time and energy con-sumption, material use and tool wear, and/or to repair damaged and high-value components, extending their useful life at a more acceptable cost (Homar et al., 2017).
The aim of this case study is to compare the performance and numerical-experimental agreement of components pro-duced by conventional methods and by additive manufacturing, after topological optimization. In addition will be demonstrated the ability to use the L-PBF to repair damage parts made conventional technologies like milling technol-ogy.

Keywords: Additive manufacturing; Powder Bed Fusion; Computer-Aided Engineering.

Acknowledgment: This work is carried out within the framework of the “Agendas para a Inovação Empresarial” (Pro-ject nº 49, acronym “INOV.AM”, with reference PRR/49/INOV.AM/EE, operation code 02/C05-i01.01/2022.PC644865234-00000004), supported by the RRP - Recovery and Resilience Plan and by the European Funds NextGeneration EU. http://www.recuperarportugal.gov.pt/.

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Topic: Additive Manufacturing
Category: Extended Abstract
Paper Number: 30601

Design for additive manufacturing hybrid products

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Abstract:

Developing new products through additive manufacturing (AM) is becoming an imperative in today's industry, mainly because AM technology enables the production of products in just one step. In AM technology products are produced layer-by-layer through a 3D file that allows the production of geometries that, by traditional technologies, would be impossible to achieve. Nevertheless, producing products by AM have some limitations, mainly when there is a need for AM parts to be assembled with major system/products, and therefore need to interact with standard or traditional manufactured parts. One paradigmatic case is when there is a need to embedded standard parts in AM products. This strategy imposes different requirements for the production phase. The final product is just one part that was assembled during the build, and therefore the manufacturing process requires (a) designing a product with a specific designed cavity to accept the external part, (b) pausing the production in the "middle" of the manufacturing process, (c) inserting the external part(s) into the designed cavity, and (d) restarting the manufacturing over the inserted part. This manufacturing strategy faces major challenges when it comes to controlling the physio-mechanical properties of the manufacturing process, especially when embedding external standard parts.

This paper presents a research to understand and developed a methodology for producing hybrid products using AM material extrusion. The study focused on the 3D modelling, dimensional accuracy, the slicing process, layer height and layer pattern, and on controlling the overall manufacturing process when embedding an external part in AM. This research will allow to understand which issues are most relevant in the process and how can they be implemented in the design of a hybrid product

Topic: Additive Manufacturing
Category: Extended Abstract
Paper Number: 30801

Process and material guidelines for large-scale additive manufacturing in part production: a case study between PP and ABS

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Abstract:

The use of robots in additive manufacturing leads to new production paradigms, emphasizing three critical factors in the production process: the manufacturing process, the material used, and the part geometry to be produced. Understanding these three factors and their respective constraints leads to better quality and efficiency in part production. In this study, programming is carried out using Grasshopper, the parametric environment of Rhinoceros®, which allows for greater process freedom through dynamic layer generation, combined with the KUKA robot's six degrees of freedom. This, combined with a polymer pellet extruder, provides flexibility and precision in process control and subsequently in parts production.
However, the material used is the primary factor that restricts the geometry of the produced parts. To explore these restrictions, a sample-part was developed to evaluate the maximum overhang angle for different materials. Four specific materials were tested: PP (polypropylene), PP combined with 30% $CaCO_3$ (calcium carbonate), ABS (acrylonitrile butadiene styrene), and ABS reinforced with 17% glass fiber. The test results provided a detailed understanding of the design limitations and capabilities of each material concerning part geometry. Subsequently, a product was produced using all four materials, allowing for an in-depth analysis of the interaction between the process, material, and geometry. This practical approach demonstrated how different materials respond to the same manufacturing parameters, providing valuable insights for optimizing large-scale additive manufacturing.
The study concludes that while the freedom provided by the use of robots and programming in Grasshopper is significant, material choice remains a determining factor in the geometric capabilities of the produced parts. The findings of this study have important implications for the future of additive manufacturing, especially in material selection and process development to maximize effectiveness and efficiency in the production of complex parts.

Keywords: Additive manufacturing; Large-scale additive manufacturing; Robot; Polymer extrusion; Design guidelines

Topic: Additive Manufacturing
Category: Extended Abstract
Paper Number: 30901

PLLA phase study by Fused Filament Fabrication

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Abstract:

Poly(L-Lactic Acid) (PLLA) is a polymer with great importance to the biomedical field due to its great mechanical properties, excellent biocompatibility, biodegradability, and piezoelectric behavior. PLLA has many crystalline polyforms, including α, β, δ, and ε, which have different properties, mainly the piezoelectric response. The electromechanical properties of PLLA are maximized in the β phase which is achieved by tensile stretching of the α phase crystals at temperatures above the glass transition temperature of PLLA. The usual method to produce β phase PLLA is by electrospinning, which produces fibers, and other methods such as mechanical pressing or drawing and filament extrusion do not have many systematical studies that show alternative ways to obtain β phase PLLA with controlled form. Furthermore, there is no study that delves into the effects of filament extrusion on the phase of PLLA, which is important for all applications of the polymer since the phases have different properties. This work was done to evaluate the effects of printing parameters such as bed temperature and extruder temperature on the obtained phases of PLLA shaped by fused filament fabrication (FFF) technology. This study focuses on the obtained phases and not on the properties, trying to use the applied forces of FFF on the printed polymer to obtain β phase PLLA. The phase is accessed by a combination of Fourier-transform infrared spectroscopy and X-ray diffraction. The crystallinity is evaluated by differential scanning calorimetry analysis. By controlling the parameters of printing, β phase PLLA was obtained successfully with varying proportions of δ phase. This work can serve as a guide for those that want to utilize the advantages of FFF while having the properties of PLLA in a controlled manner.

Keywords: PLLA; FFF; Piezoelectric; β phase; crystallography;

Topic: Additive Manufacturing
Category: Extended Abstract
Paper Number: 31001

Moulds and mould making innovations A

Assessing Geometric Deviations in Plastic Parts: A Study between Conventional and Conformal Cooling Channels in Metal Molds Produced by Additive Manufacturing

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Abstract:

The cooling phase on an injection molding process is crucial to warranty lower warpage and shrinkage on the molded parts, besides assure the process productivity. Cooling channels manufactured inside the mold's cavities is responsible to chill the parts before the end of the cycle. Today, these channels are ordinarily manufactured by drilling machining, what only allows to fabricate linear holes. Thus, in most of the cases, the heat transfer homogeneity is difficult to reach. The advent of the additive manufacturing technology of metal parts allows the possibility of manufacturing Conformal Cooling Channels (CCC) inside a mold of metal. The current work investigates the impact on the dimensional accuracy of molded parts using both kinds of molds. It was used an automotive plastic component as the workpiece (**Fig. 1a**). A mold was designed for this investigation (**Fig.1 b**). Two exchangeable inserts of mold`s were manufactured, first one using conventional cooling channels (**Fig. 1c** (iii)) and the second one using CCC manufactured by additive manufacturing technique (**Fig. 1c** (iv)). Two baches of plastic parts were produced, first using the conventional mold and then the mold with CCC.

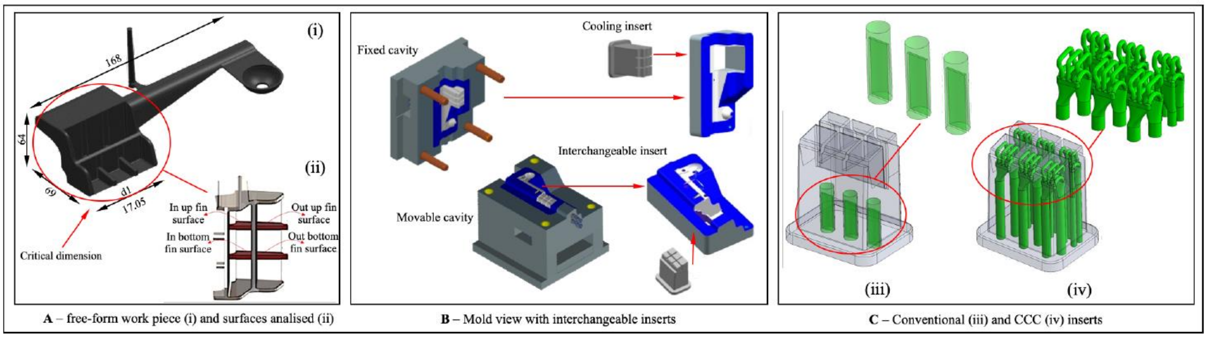
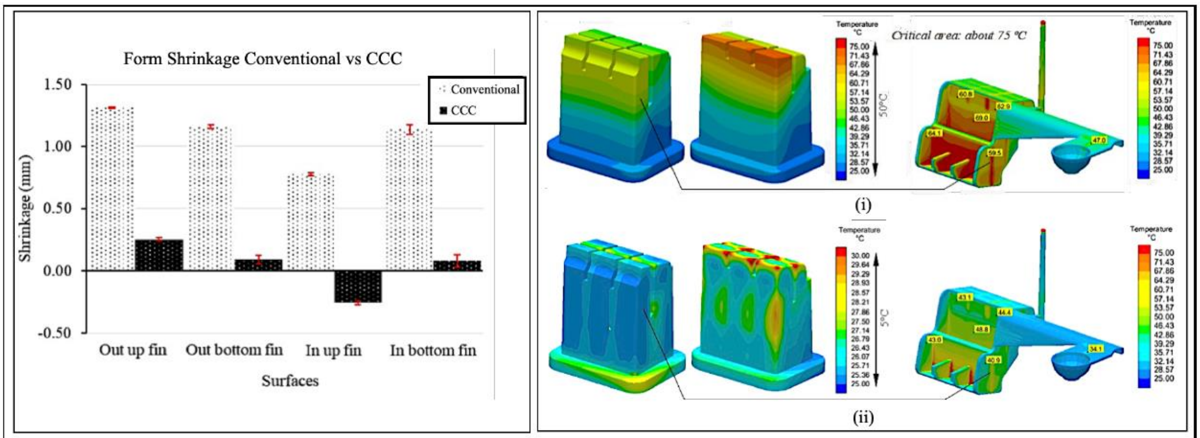


Figure 1. (a) isometric view of the free-form workpiece (i) and detailed front view of the surfaces that manifested the occurrence of shrinkage (ii); (b) injection mold with its fixed and moveable cavities and interchangeable inserts; (c) conventional (iii) and CCC (iv) inserts and its detailed channel's view.

The geometry deviation was assessed by a coordinate measuring machine (CMM) against the three-dimensional design. Computer-Aided Engineering (CAE) software was also employed to analyze the three-dimensional model, which validated the deformations detected by the CMM and illuminated the heat exchange during the molding process using both molds. Using a mold with CCC resulted in an average shrinkage reduction of 96.36%, related to BCC (**Fig. 2a**). The inserts exhibited higher temperatures (approx. 200% for BCC and 20% for CCC) on the tip contrasted to the rest of the body, where significant shrinkage effects were observed (**Fig. 2b** (i)) as well as an increase of approximately 43% was observed on the parts critical area (**Fig. 2b** (ii)).



A – Average shrinkage values for conventional and CCC parts and its standard deviation

B – Average shrinkage values for conventional (i) and CCC (ii) parts and its standard deviation

Figure 2. (a) values and standard deviation of surfaces that have experienced shrinkage according to CMM; (b) CAE part temperature gradient for injection mold with conventional (i) and CCC (ii) & inserts temperature rate for traditional (i) and additive (ii) manufacturing.

Based on the findings, CCC inserts demonstrated superior dimensional consistency and precision compared to BCC. This advantage arises from the uniform cooling homogeneity, resulting in a more consistent cavity pressure profile.

Keywords: injection molding; dimensional precision; product excellence; cooling channels; additive manufacture

Topic: Moulds and Mould Making innovations A
Category: Extended Abstract
Paper Number: 30302

Balancing heat extraction rates on injection moulding tools through smart temperature control design

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Abstract:
The investigation and implementation of new tailored temperature control systems (TCS) produced by additive manufacturing (AM) is growing rapidly. Nevertheless, their design is challenging and requires new project rules with a compromise between thermal and structural performance. Accordingly, the study of the thermal, fluidic and mechanical processes, in particular how these processes are linked in the TCS design and how they affect part quality, productivity and tool life, can lead to the development of these new project rules. To this end, the relative influence of different variables such as channel diameter, channel position (distance between channel centreline and mould wall and channel pitch) and coolant flow rate, were analytically investigated. Overall, it was found that two heat transfer mechanisms, namely conduction and convection, influence the final cooling time and impact part quality, with conduction being mainly influenced by channel position (distance between channels and between channel and mould wall) and channel diameter, while convection is influenced by coolant flow rate and channel diameter. In a previous study, the authors evaluated and numerically ascertained the impact of channel diameter and position on the final cooling time and part quality, and the conclusions were consistent with those of the analytical study. Regarding the coolant flow rate, the analytical study has shown that an increase in the coolant flow rate results in an increase in the convective heat transfer, which can lead to a reduction in the cooling time. Nevertheless, it is important to mention that due to the thermal inertia of the polymer, i.e., "property of a material that expresses the degree of slowness with which its temperature reaches that of the surroundings", which depends on its absorptivity, specific heat, thermal conductivity, and dimensions, a point may be reached where an increase in the coolant flow rate does not result in a reduction in cooling time. Consequently, proper balance between convection and conduction must be studied, as the maximum heat transfer by convection may be reached and other solutions, such as maximising heat transfer areas, by increasing the channel diameter, may be necessary to reduce cycle time and improve part quality. Moreover, although this simplified analytical model assumes spiral or zig-zag cooling channel, other cooling channels layouts designed based on Voronoi Diagrams (VD) have been studied.

Cooling channels based on VD are an interesting channel layout solution particularly due to their complex connectivity, these channel ramifications, if properly balanced, can lead to better part quality, as the coolant temperature in the circuit can present lower variations, which can result in the same temperature difference between part and coolant throughout the part, crucial to attain better part quality. Proper balance between heat transfer and fluid flow includes reaching an uniform heat extraction rate by ensuring a good coolant flow distribution within the channels, which in this case, has to be achieved through a proper design of the collector and the channels of the different branches, to minimize pressure losses.

Consequently, in order to assess the impact of the VD layout designed, a numerical case study was proposed and analysed. The study used an HDPE acetabular cup to be produced by injection moulding and Autodesk Moldflow Insight® (AMI) software, via Finite Element Method (FEM) transient in cycle analysis, was used to assess the impact of VD layout on cycle time and part quality. Moreover, the study also presents the analysis on how different flow velocities impact on part quality and heat extraction rate. To ensure proper process settings and guarantee minimum cycle time and part maximum quality a Design of Experiments (DOE) approach was undertaken and the selected TCS for this case study was based on the VD. It is worth mentioning that when designing a channel layout based on the VD flow balance throughout the channels must be assured, to attain a more uniform heat removal and, hence, more uniform temperature distributions, which leads to a better part quality.

With the part, TCS and process conditions selected for all the numerical studies, different coolant flow rates were further evaluated. The results showed that the coolant flow rate affects the heat extraction rate, which inevitably affects the cycle time and temperature distribution, thus affecting productivity and part quality. Furthermore, the results attained are consistent with those expected by previously depicted analytical assessments and similar studies seen in the literature.

Keywords: temperature control system; thermal model; heat extraction balance; coolant flow rate; injection moulding

Topic: Moulds and Mould Making innovations A
Category: Abstract
Paper Number: 30402

Optimizing Ejection of PLA-Based Compounds from Hot Core-Shell Molds: Experimental Investigation and Process Modelling

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Abstract:

PLA is a bio-based and biodegradable polymer that has been gaining much attention for several applications, including packaging, disposable tools, and medical devices. PLA products are usually manufactured by injection molding, allowing high-volume production. For PLA products to have improved mechanical and thermal properties, the polymer must be highly crystallized. This is usually done by keeping the PLA inside a hot mold for a long cycle, which allows the crystallization to develop, or by applying post-mold annealing methods such as microwave heating, oven heating, or IR heating.

In-mold annealing is an efficient and cost-effective method for inducing crystallization and achieving higher crystallinity in PLA parts. In this case, it is desirable to eject the part as quickly as possible to minimize cycle time and have it still hot, which can be further crystallized outside the mold under controlled conditions. However, it is challenging to eject the hot part from the mold because the ejector pins can make deep pin marks. Additionally, the material can be too compliant to maintain the part shape.

To eject the part from the hot mold, two main obstacles must be overcome: minimizing the friction of the part with the mold and handling the part to maintain its shape and prevent deformation. Regarding the first issue, friction is correlated with normal force and the friction coefficient. The normal force depends on part shrinkage (related to polymer crystallization), where higher shrinkage results in a higher normal force when using a core-shell-like mold design. Therefore, the fast demolding of parts made of PLA compounds is a complex problem that requires the investigation of several interconnected material properties and process parameters.

In this study, interchangeable mold inserts having cores with different draft angle values were used to study the molding conditions that allow for fast ejection experimentally. To decrease the friction coefficient, we investigated molding different PLA-based materials that have varying shrinkage behaviors due to different crystallization rates and formulations, which include release agents.

The sample parts were molded using a micro-injection molding machine operating with hot mold conditions (90°C). The mold had a load cell behind the ejectors to measure ejection force. Additionally, the depth of the ejector pin marks was measured at different process conditions. These measurements (ejection force and the depth of ejector pin marks) were utilized to evaluate the stiffness of the parts upon ejection. Furthermore, the crystallinity of the molded samples was assessed using differential scanning calorimetry (DSC). By integrating this data, the ejection process was modeled to optimize the processing conditions.

In conclusion, using all the experimental data, the model was fitted to these data, and the results were used to optimize the processing conditions and minimize the cycle time. To our knowledge, this is the first study that thoroughly investigated and attempted to optimize the ejection problems of PLA-based compounds in hot core-shell-like molds.

Keywords: Injection molding; PLA; Ejection; Demolding; Crystallization; Stiffness

Topic: Moulds and Mould Making innovations A
Category: Extended Abstract
Paper Number: 30502

Developments in the Rotational Moulding of Hydrogen Tank Liners

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Abstract:

In the generation, delivery, and end use of hydrogen as a future energy source, there is a growing need for lightweight storage vessels. Traditionally there are a variety of gas storage tank types based on the materials that they are manufactured from, but the most common type for lightweight tanks is type IV. Typically, these are made from a polymer liner with integrated metal bosses that is overwound with a fibre-reinforced composite to provide its ultimate strength. While the polymer does not contribute strength, it plays vital roles in providing the shape for winding, securing and integrating the metal bosses, and in controlling the permeation of gas through the walls of the tank. The main techniques for the production of tank liners include blow moulding and rotational moulding with the major polymers being different grades or blends of polyethylene and nylon. In this work the rotational moulding process for polymer liners was investigated in an attempt to optimise the design and manufacturing steps. In particular, the work examined the integration of the metal boss components during the moulding process and how to adapt the design of parts to achieve optimum results. Encapsulation of the metal components is of crucial importance for both mechanical performance and in creating a reliable seal to prevent the formation of leak paths. Good design is critical to this along with detailed understanding of how the moulding process may be adjusted to redistribute polymer to the areas needed. The work undertaken included a combination of computer-aided design and modelling to create candidate designs, followed by detailed moulding trials to create prototype parts for physical evaluation. Boss designs for investigation were manufactured using a combination of conventional machining and rapid prototyping techniques. These were optimised to balance the need to retain metal for strength against the need to minimise its weight and its cooling effect on the polymer during moulding. The work was carried out using the latest robotic rotational moulding platform (AMS Robomould), where the mould is electrically heated and its movement is controlled through a robotic arm.

Keywords: Rotational Moulding; Hydrogen Liner; Type IV Tank; Robotic.

Topic: Moulds and Mould Making innovations A
Category: Abstract
Paper Number: 30602

Moulds and Mould making innovations B: Hybrid Moulds

Influence of different surface coatings on polymeric inserts for hybrid injection molding of reinforced PBT

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Abstract:

Hybrid Moulds arose from the need to obtain parts more quickly for the market, combining additive and subtractive processes with the aim of reducing costs, time-to-market, energy consumption and waste. Optimizing the layout of the cooling system using conformal cooling channels can help reduce visual defects in parts, such as warpage and sink marks. Polymeric moulding inserts produced by Additive Manufacturing (AM) present some problems, such as low durability, scarce availability of AM polymeric materials on the market, low heat transfer of existing polymeric materials, prone of adhesion between the materials to be injected and the molding inserts, poor surface quality, inaccurate dimensional tolerance, the impossibility of placing channels in the molding inserts for thermal control and limitations in the injection of parts with complex geometries.

One way to improve the performance of polymeric inserts is to apply surface coatings, which will improve the surface quality of the molding inserts, as well as prevent adhesion between the material of the molding inserts and the material to be injected, facilitating the extraction of the parts, solving some of the problems identified.

This study aims to compare the thermal and mechanical behavior of polymeric molding inserts, with and without the application of surface coatings, during the injection molding process using hybrid molds. The injection material selected for this type of application is a PBT reinforced with glass fibers, ideal for parts in the automotive industry, which require greater fire resistance (e.g.: potentiometer parts, plug-and-socket connectors or switches).

Keywords: Hybrid Mould, Additive Manufacturing, Moulding Inserts, Stereolithography, Surface Coating, Conformal Cooling.

Acknowledgment: This work was carried out within the framework of the “Agendas para a Inovação Empresarial” [Project nº 49, acronym “INOV.AM”), supported by the RRP - Recovery and Resilience Plan and by the European Funds NextGeneration EU. http://www.recuperarportugal.gov.pt/.

Topic: Moulds and Mould Making innovations B: Hybrid Moulds
Category: Extended Abstract
Paper Number: 30802

Study of thermoplastics polymers applied to the extrusion additive manufacturing for naval industry moulds

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Abstract:

The development and growth of manufacturing technologies is driven to reduce cycle times, increase the availability of customised products and focus on factors such as sustainability in product development. On the other hand, in the production of marine mobility products, it should be noted that the technologies currently used for mould production are essentially based on conventional methods. However, there is a potential to use large-scale hybrid manufacturing systems (additive and subtractive) for this purpose. These systems should be able to produce moulds for the naval industry with suitable quality. This study focuses on the selection of thermoplastic polymers, including recycled and fibre-reinforced thermoplastics, to be used in large-scale additive manufacturing through the extrusion process, for the production of boat moulds. The materials were mechanically and thermally characterised and their experimental behaviour was assessed under certain operating conditions. The most suitable type of the support base was also ana-lysed to allow better adhesion of the first layer of polymer. Since today's needs are based on development supported by circular economy principles, it is of the utmost importance that the products developed are recyclable when they reach the end of their useful life.

Keywords: Additive Manufacturing, Extrusion, Thermoplastics, Large-Scale, Naval Moulds, Composites

Acknowledgements: This work is carried out within the framework of the “Agendas para a Inovação Empresarial” (Project nº 49, acronym “INOV.AM”, with reference PRR/49/INOV.AM/EE, operation code 02/C05-i01.01/2022.PC644865234-00000004), sup-ported by the RRP - Recovery and Resilience Plan and by the European Funds NextGeneration EU. http://www.recuper-arportugal.gov.pt/

Topic: Moulds and Mould Making innovations B: Hybrid Moulds
Category: Abstract
Paper Number: 30902

Investigation of the injection molding process using different concepts of molds: i) conventional cooling, ii) conformal cooling, iii) molds with high thermal conductivity (CuBe).

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Abstract:

The injection molding process for plastic parts with thicker walls requires special attention, as the cooling phase takes longer than that of common products. It drastically influences the part`s properties and the productivity. Tubes to transport fluids with high temperature are examples of such products with thicker walls. The advance of additive manufacturing of metal parts has been arising the possibility of manufacturing molds containing free form cooling channels, known as conformal cooling, it can improve the heat transfer during the molding process, then it benefits the plastic part`s properties besides reducing molding cycle time. Such benefits of the use of conformal cooling molds can be found on the current literature, in general for product with conventional wall thickness. But the additive manufacturing process is relatively expensive, it might require extra post-process of manufacture and the design of the conformal cooling systems is not well established yet. Thus, the industrial usage of molds with conformal cooling manufacture by additive process is still limited. Alternative materials with high heart exchange to manufacture molds by the conventional way (machining) might also propitiate the benefits of high heat transfer rate without the face the challenges of the additive manufacturing process and conformal cooling design. Considering this background the current work investigates by CAE simulations the heat transfer and molding process to produce plastic parts of thicker walls using molds with con-formal cooling manufacture with the SS 316L and conventional mold manufactured by machining using CuBe alloy to improve the heat transfer. The results show an expressive reduction on the molding cycle time for the molds of SS 316L with conformal cooling as well as with the mold manufactured conventionally with CuBe material. In both cases, the part`s deformation reduced significantly if compared with the parts produced using the mold of SS 316L with conventional cooling channels. The use of CuBe alloys to manufacture the mold saved significantly the manufacturing time and all the costs involved on the mold`s manufacturing phase, proving to be a strong competitor against the additive manufacturing process to produced molds with conformal cooling channels.

Keywords: injection molding; conformal cooling; additive manufacturing; CuBe alloys.

Topic: Moulds and Mould Making innovations B: Hybrid Moulds
Category: Extended Abstract
Paper Number: 31002

Trends in Product Development

Study of pine resin collection bag properties to develop a more environmentally friendly system

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Abstract:

Pinus pinaster occupies more than 20% of the forest ecosystem area in the continental territory of Portugal with a high impact on its economy. One of the major derived products is oleoresin, the raw material for rosin production. Pine resin distillation is a process that makes it possible to obtain a liquid fraction called turpentine and a solid fraction known as rosin. Rosin is the main component of the extracted resin. It is composed mainly by acids (90%) and by small amounts of neutral compounds (10%). Although the composition of resin acids may vary depending on the pine species, they usually are abietic–type acids. These abietic acids are very unstable compounds. This fact is the reason why rosin tends to get darker, to solidify and lose its chemical and physical properties when exposed to light and air. Natural resin is a natural and high value source for applications in glues and varnishes, food, pharmaceuticals and cosmetics industries. The main issue with the current collection methods that rely on open containers is the high contamination of the resin by debris from the forest and the evaporation of its highest value component (turpentine). This significantly de-creases the quality of the resin and presents difficulties at the factory, as the resulting product is also crystallized and difficult to process. Hence, it is important to improve and modernize the production and collection processes and procedures. This work aims the development of an advanced protocol to optimize the reuse of the newly developed collection bags through correct and efficient washing. This procedure will enable the removal of the resin that remains after the initial extraction, making it possible to reuse the bags or to recycle them. This study includes physical and chemical tests and assays to study the effect of several washing procedures. The results obtained with Infra-Red and Sonochemistry tests contributed for a new bag design and a new protocol for the washing of plastic bags were found.

Keywords: Oleoresin collection, Rosin, Polymers, FTIR-ATR assays, Ultra-sound frequencies

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Topic: Trends in Product Development
Category: Extended Abstract
Paper Number: 31401

How do we go from PO in PMD bags in Belgium to recycled products?

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Abstract:

In order to bring sustainability to the next level and comply with current and future legislation, it is essential that we collect, sort, recycle, and reuse polymer raw materials as much as possible. The targets for Europe are challenging, yet clear: by 2025 we need to recycle 55% of plastic packaging and by 2030 all plastics packaging needs to be recyclable.

The different companies within Ecoo have the purpose to contribute to society by preserving natural resources and creating a better future for the generations to come, which fully supports these European targets. Benefitting from the sorting scheme of Fostplus, a Belgian organisation that has been driving circular economy in Belgium for almost 30 years, Ecoo Recycling is responsible for the conversion of mixed polyolefin fraction from the PMD bag, commonly referred to as the 'blue bags'. These blue bags are used to collect post-consumer packaging consisting of cardboard-derived materials such as Tetra, plastic packaging like bottles, films, bags, trays; and metal-based packaging materials. Besides the activities in Houthalen, Ecoo has built a new recycling plant in Beringen where the LDPE film fraction from the blue bag is recycled to a LDPE regranulate that is repurposed as feedstock for film production. The recycling processes result in MPO regranulate on one hand, and LDPE regranulate on the other hand, both fully recycled raw materials. These regranulates are either sold to third parties or further processed by Ecoo BV. This is the production center where the recycled materials are converted into end products using injection molding, extrusion and intrusion.
Ecoo New technologies was founded in 2021 considering the strategic importance of research and quality in recycling, and is focused on developing innovative technologies to measure and guarantee the quality of recycled materials.
The vicinity of the different companies has the advantage that a local ecosystem is formed with easier logistics, operational flexibility, and optimal quality control by eg. mixing several regranulates to tune product properties, while minimizing the ecological footprint. This further supports the way to circularity and sustainability.

The expertise in converting MPO and LDPE regranulates from the ecoo recycling plants into end-products has led to the development of 100 % recycled and recyclable products such as compost bins, boarding, benches, etc., Also new higher-end products like T40-grid for permeable paving are completing the portfolio and further supporting the strategy of ecoo BV.

It is Ecoo's ambition to keep up with the demand in the recycling of plastics and produce high-end products. Quality control is essential to achieve this. Ecoo New Technologies keeps driving towards a fast (second-scale), online and non-biased quality control system, and hence is supporting the ecosystem.

Keywords: mechanical recycling, circular economy, quality control & challenges, post-consumer

Topic: Trends in Product Development
Category: Abstract
Paper Number: 31501

Advanced design of meta-structures through additive manufacturing: A Review

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Abstract:

Metamaterials have garnered significant attention in recent years due to their ability to manipulate electromagnetic waves, acoustic waves, thermal conduction, and mechanical forces in unconventional ways. Unlike conventional materials, the properties of metamaterials are derived from their meticulously engineered internal structures, designed to exhibit specific behaviours. A scoping search methodology was used to conduct a literature review, assessing the current development of metamaterials and their production using additive manufacturing (AM) technologies. This review aims to provide a comprehensive overview of metamaterials, highlighting their distinctive characteristics, engineering applications, and the advanced fabrication techniques employed in their creation.
The defining feature of metamaterials is their engineered internal structure, which gives rise to their unique properties. These properties result from the specific arrangement of unit cells within the material, often at the microscale or nanoscale, also known as meta-structures. Metamaterials have a wide range of applications across various fields, owing to their ability to manipulate different types of waves and forces, and can be classified as electromagnetic, acoustic, mechanical, and thermal metamaterials. Electromagnetic metamaterials manipulate electromagnetic waves, achieving negative permittivity and permeability, and can be used to create super lenses, cloaking devices, and advanced antenna designs. Acoustic metamaterials have the ability to control sound waves, leading to innovations in soundproofing, acoustic lenses, and vibration control. Mechanical metamaterials are known for their unusual mechanical properties, such as negative Poisson's ratio, and are primarily used for impact protection applications, flexible electronics, and soft robotics. Thermal metamaterials manipulate heat flow, providing applications in thermal management, such as heat cloaking and more efficient thermal insulation. Recent research in metamaterials has focused on enhancing their mechanical robustness, scalability, and multifunctionality. Computational models and simulations play a crucial role in designing and optimizing these materials for specific applications, with experimental validations essential to ensure that theoretical predictions are practically achievable.
Additive manufacturing (AM), commonly known as 3D printing, plays a pivotal role in the fabrication of metamaterials. AM techniques enable the precise control and design of complex internal structures essential for the unique properties of metamaterials. The flexibility and precision offered by AM are unmatched by traditional manufacturing methods, making it indispensable in the development of metamaterials. In this context, key contributions of AM include the ability to create intricate geometries and complex structures, the support for a wide range of materials including metals, polymers, and composites, and the fact that it facilitates rapid prototyping and iterative design, allowing the fine-tuning of meta-structures and hence the metamaterials properties in order to meet specific requirements. Innovations in AM continue to expand the possibilities for metamaterials, enabling their use in increasingly diverse and demanding applications.
Metamaterials represent a significant advancement in material science, offering unprecedented control over a wide range of physical phenomena. Their unique properties open new possibilities in various fields, from telecommunications to aerospace. Ongoing research and development efforts are likely to further enhance the capabilities and applications of metamaterials, solidifying their role as a cornerstone of modern engineering and technology.

Keywords: Additive Manufacturing, 3D Printing, Metamaterials, Meta-structure Design, Rapid Prototyping.

Topic: Trends in Product Development
Category: Extended Abstract
Paper Number: 31601

PLA degradation during single-screw extrusion: predicting the effect of PLA-grade, die geometry and screw design on the molecular weight

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Abstract:

Due to environmental challenges and waste pollution problems, an increased interest and usage of aliphatic biopolyesters is seen. With poly(lactic acid) or PLA as the most popular biopolyester, it can serve as a suitable alternative to conventional polymers for specific applications. During melt processing of PLA, it is challenging to maintain a high quality material due to its sensitivity to degradation. Exposure of PLA granules to moisture, high processing temperatures and shear stresses is linked to hydrolytic, thermal and mechanical degradation. Consequently, random chain scission of the polymer chains may occur and will affect its molecular weight. To avoid this decrease of the material quality and to understand how PLA should be efficiently processed, a predictive model can help processors and researchers working with this polymer.

The aim of this study is to predict degradation of PLA during single-screw extrusion with a kinetic degradation model and thereby understand how the molecular weight is affected. First, the kinetic model is set-up, based on data of an experimental study that investigated the effect of four processing parameters (moisture content in the granules, processing temperature, residence time, and shear stresses). The extrusion screw, PLA-grade and die selection (all capillary dies) are constants and are not varied during these measurements. Second, the applicability of this kinetic model is tested when the extrusion screw geometry, the PLA-grade and die selection are varied. Experimental data of processing two other commercial PLA-grades, a tube die and a screw with a shorter compression zone is used to check the validity of the kinetic degradation model. The results of this study allow PLA processors to effectively select processing conditions and thereby maintain a high quality material, ultimately saving time and money during production.

Keywords: PLA; poly(lactic acid); degradation; kinetic degradation model

Topic: Trends in Product Development
Category: Extended Abstract
Paper Number: 31801

Design and Development of a Capillary Blood Collection Device for Global Disease Diagnosis and Monitoring

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Abstract:

Blood analysis, including density measurements of white blood cells, red blood cells and hemoglobin, is one of the most ordered clinical tests. It provides valuable information for evaluating overall health and diagnosing various diseases. Typically, a blood test requires the use of specialized equipment and personnel. The need for efficient, minimally invasive diagnostic tools is paramount. This study presents the development of a volume-controlled capillary blood collection device, utilizing microfluidic technology, offering a user-friendly solution for both clinical and at-home settings. The primary objective of the study was to develop a product capable of efficiently drawing biological fluids, which is influenced by three critical factors: material selection/properties, geometric design, and processing conditions (i.e. molding tools). The research process began with an in-dept analysis of geometric factors through additive manufacturing. Some samples were developed and tested demonstrating material excellent results. However, due to the high production volumes required, is not viable for large-scale manufacturing. Subsequently, these initial tests identified the optimal geometry for fluid collection, and a mould was developed that allows for variations in the entry geometry and analysis zone. These variations were considered in order to adapt parts of the geometry to test new solutions. Computational simulations and contact angle measurements were conducted to evaluate different materials. Based on the results, three materials were initially tested: HydroPLA, PMMA Plexiglas 8N and PMMA Plexiglas 7N. Among these, HydroPLA emerged as the most promising material due to its superior hydrophilic properties although very expensive. Consequently, ongoing tests are planned to evaluate the effectiveness of using a blend of HydroPLA and standard PLA at varying percentages to assess feasibility and cost-effectiveness. Future research will focus on refining material blend and optimizing the manufacturing process.

Keywords: blood analysis; hydrophilic materials; additive manufacturing; product design.

Topic: Trends in Product Development
Category: Extended Abstract
Paper Number: 31901

Polymeric Composites

Exploring the Thermal and Mechanical Characteristics of Polymers with Recyclable Fillers: A Case Study

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Abstract:

The substitution of conventional polymeric materials with sustainable or biodegradable alternatives presents a promising field in material innovation. In order to achieve this goal, alternative materials must maintain or improve the mechanical and thermal properties of the base material, which must be appropriate for their intended application. The present study focuses on the use of polypropylene and polystyrene, materials widely used in the automotive sector, reinforced with other materials (namely graphite, clay and polylactic acid (PLA)) and the effect of use of these sustainable and biodegradable fillers on injection moulding process. Two of the topics on the agenda are sustainability - the ability to meet our needs in the present without compromising the ability of future generations to meet their own needs - and the circular economy - a strategic concept based on the reduction, reuse, recovery and recycling of materials and energy. These new approaches aim to replace the end-of-life concept typical of the linear economy with circular flow strategies of reuse, restoration and renewal in an integrated process. The aim of this work is to analyse and understand how biodegradable or sustainable materials such as graphite, clay and polylactic acid (PLA) affect mechanical and thermal behaviour when incorporated with a polypropylene and polystyrene matrix in low percentages (from 3 to 15%). The experimental procedure consisted of producing standard specimens for testing in the laboratorial environment by injection moulding, which enabled various mechanical and thermal tests to be carried out, namely tensile, bending and Shore hardness tests, as well as determining the density of each material, its fluidity index and differential scanning calorimetry (DSC) tests.

Keywords: injection moulding; sustainable and biodegradable polymeric materials; mechanical and thermal analysis

Topic: Polymeric Composites
Category: Extended Abstract
Paper Number: 31402

Manufacturing of PA-based filaments reinforced with chopped carbon fibres for 3D printing applications

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Abstract:

This research study investigates the manufacturing of polyamide (PA)-based filaments reinforced with chopped carbon fibers (cCFs) for 3D printing applications, aiming to optimize the production process and enhance the performance of printed components. Two compositions, containing 10% and 15% wt. cCFs in PA6/66 and PA12 as polymer matrices, were developed and evaluated. The compounding process was conducted using a twin-screw extruder (TSE) with a 40 L/D ratio and 8 independent heated zones, enabling precise control of temperature across each zone. It was observed that higher concentrations of cCFs increased the processing difficulty, characterized by higher torque and pressure requirements, underscoring the need for optimized extrusion parameters. In the subsequent 3D printing phase, key parameters such as printing temperature, layer height, and printing speed were systematically varied to determine the manufacturing efficiency of the printed parts. Tensile testing was carried out in order to compare the mechanical properties of the printed parts (100% infill) with similar specimens produced via injection moulding. The results indicated that the PA/cCFs composite filaments exhibited significant potential for producing high-performance components via Fused Filament Fabrication (FFF). This study provides valuable insights into the relationship between material composition, processing conditions and the resulting properties of the printed parts, highlighting the applicability of PA/cCFs composites in demanding industries, particularly the automotive sector.

Keywords: Chopped Carbon Fibers; Compounding; Extrusion; Fused Filament Fabrication; Polyamide; Thermoplastics

Acknowledgements: This work was funded under the EU funded research programme, entitled: “European recycling and circularity in large composite components” (EuReComp), under Horizon Europe with GA No. 101058089.

Topic: Polymeric Composites
Category: Extended Abstract
Paper Number: 31502

Biopolymer filament with coffee silver skin for Fused Filament Fabrication (FFF) printing

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Abstract:

Coffee is one of the most popular beverages all over the world, meaning that several million tons of coffee silver skin (CSS) are produced every year by the coffee roaster (McNutt & He, 2019). Despite some actual applications for CSS, such as fertilizer, large amounts are still deposited in landfills. Therefore, the development of new applications for CSS, will add value to this bio-waste and, simultaneously, generate new business opportunities. The aim of this work was to produce and characterize 3D printing filaments for FFF using the Inzea® F38 - (PLA+PSAC) - Nurel S.A with coffee silver skin (CSS). Were produced composites with different percentage of CSS and evaluated the extrusion capacity of the filament, the mechanical properties, allowing the filament to be used in FFF machines, and it ability to manufacture parts. Was also evaluated the influence of CSS in the boning behavior between adjacent filaments and the mechanical properties of dogbone samples. The results sows that all the composites are able to produce filaments to be used in FFF technique. As expected, the CSS improve some mechanical properties, as Young modulus and the tensile strength. The results also shown that CSS has reduce effect in the bonding behavior.

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Keywords: Fused filament fabrication; coffee silver skin; bio-based materials; mechanical properties.

Acknowledgment: This work was carried out within the framework of the “Agendas para a Inovação Empresarial” [Project nº 49, acronym “INOV.AM”), supported by the RRP - Recovery and Resilience Plan and by the European Funds NextGeneration EU. http://www.recuperarportugal.gov.pt/.

Topic: Polymeric Composites
Category: Extended Abstract
Paper Number: 31602

Sustainable carbon fiber precursors produced from lignin blended with biobased polyamides.

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Abstract:

Lignin is considered to be one of the most attractive biomaterials for sustainable development, being the second most abundant biobased resource after cellulose [1,2]. Many efforts have already been made in an attempt to utilize lignin as a biomaterial, especially in the preparation of carbon fiber precursors due to its high carbon content.
Lignin-based precursor fibers can be prepared through melt-, solution or electrospinning. Melt spinning has an unparalleled advantage with respect to price and environment cost, because of the relatively high processing speed involved and the absence of solvent [3]. By blending lignin with (bio)polymers, the scalability can be improved. Several polymers have already been explored towards melt spinnability into precursor fibers in combination with lignin: PP, PET, TPU, PLA, PA ... [4-9].
Precursors based on immiscible PP and PLA blends however resulted in hollow or porous carbon fibers. PET and TPU have a good miscibility with lignin, but the high melting point of conventional PET adversely affects lignin degradation. Its biobased alterative PEF (polyethylene furanoate) could be more suitable, but it is still not commercially available and not yet (well) investigated with respect to lignin blending. The use of TPU on the other hand leads to problems with melt spinnability, o.a. due to its elastic behavior.
The PA blends tested by Muthuraj et al. [8,9], involving biobased PA11, PA1012 and PA1010, were not fully miscible but had a good melt spinnability. The lower miscibility also did not result in porosity of the carbon fibers, as was the case for PP and PLA. In the SUSPENS project (GA 101091906), the research on PA-lignin blends production is therefore continued. This involves additional research on PA11, as well on two novel biobased PA's with an odd-numbered carbon molecular structure: PA 5.10 and PA5.13 [10]. As lignin grade, a hydrolysis type of European origin was used, exhibiting a thermoplastic behavior. Compounding and melt spinning trials are performed on semi-industrial equipment. Blends with 50% lignin content were melt spun into fibres, containing up to 47,5% lignin content after minor dilution The current yarns have a thickness of 120 dtex and consist of 24 filaments. Further trials intend to further increase the lignin content and the number of filaments. Simultaneously, stabilisation and carbonisation trails are ongoing.

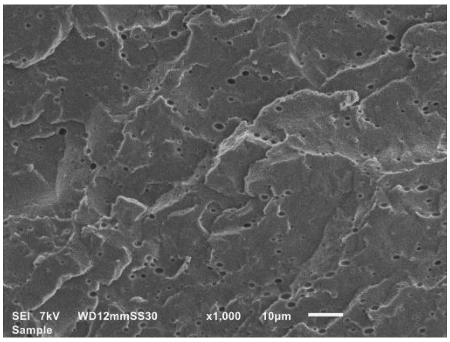

Figure 1: SEM of the PA5.13-lignin compound (left), precusor fibres made from this compound (right)

Keywords: lignin, biopolyamide 5.10 and 5.13, sustainable precursor carbon fibres

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Topic: Polymeric Composites
Category: Extended Abstract
Paper Number: 31802

Design For Manufacturing – The Integrated Workflow

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Abstract:

The presentation outlines an integrated workflow for Design for Manufacturing (DFM). The workflow integrates CAD design and simulation using Moldex3D for pre-processing, parameter settings, and process optimization. An API-driven approach is used for determining gate locations, flow balance, and warpage control. The process includes iterative simulations to enhance design and manufacturing efficiency. Advanced optimization techniques, including gradient-based and stochastic-based methods, are discussed for achieving local and global optima. The workflow aims to streamline the transition from design to manufacturing, leveraging automation and optimization for improved industrial applications. Future directions include machine learning integration for enhanced data visualization and process inspection.

Topic: Polymeric Composites
Category: Extended Abstract
Paper Number: 31902

Poster Presentations

The influence of post-industrial and post-consumer recycling during Fused Filament Fabrication of PETG

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Abstract:

Fused Filament Fabrication (FFF) is a commonly used additive manufacturing technique in which filament is extruded through a heated nozzle onto a heated printer bed. In this manner the desired part is produced layer by layer. This technique benefits from its ability to create highly specific parts in small amounts, which is not possible with conventional techniques such as injection molding. However, some challenges still occur such as material choice, definition of the printer settings, as well as the sustainability aspect.

As polyethylene terephthalate (PET) is a commonly recycled material, this could be an interesting option for FFF. However, amorphous materials are desirable for 3D printing, as these materials are less susceptible to shrinkage and consequently deformations. An amorphous alternative for PET, namely PETG or polyethylene terephthalate glycol, is in this case a better option. Nowadays this material is already used for 3D printing, however, assessment of its recyclability is needed to decide if this material is a sustainable option for FFF. For this purpose, four PETG grades, namely a low viscosity, medium viscosity, high viscosity and high mechanical properties grade were investigated.

Filament was produced from each grade and used for printing with a commercial Prusa i3 MK3s printer. Printing temperatures were varied between 215 and 270 °C, whereas printing speeds were varied between 10 and 100 mm/s. Post-industrial recycling was simulated by adding up to 40 weight% recycled PETG content from the filaments inside new filament for each grade. To simulate post-consumer recycling, PET water bottles were collected, cleaned and shredded, and added inside new PETG filament by 40 weight%.

From the results could be concluded that higher printing temperatures and lower printing speeds have a positive effect on the mechanical properties. The influence of post-industrial PETG waste was neglectable for the medium viscosity, high viscosity and high mechanical properties grade. For the low viscosity grade, 20% post-industrial recycled content increased the mechanical properties whereas 40% decreased the product's quality. The introduction of post-consumer PET waste had a negative effect on all grades, especially on the high mechanical properties grade, while the high viscosity grade was the most resistant to a decrease in quality.

Keywords: Fused Filament Fabrication; co-polyesters; sustainability; recyclability.

Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2413

Exploring the potential of using DEM for studying the thickness distribution of rotational moulded parts

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Abstract:

This study leverages the Discrete Element Method (DEM) to simulate powder flow within a mould during rotational moulding, utilizing Ansys Rocky software. Initial simulations focus on uniaxial rotational moulding to establish baseline behaviours and validate the methodology. Subsequently, the simulation framework is extended to more complex robotic rotational moulding processes. The research explores the impact of varying particle sizes on flow dynamics and assesses the relationship between particle quantity and computational time. Results indicate that downsizing the mould and reducing particle count can effectively model the process, as demonstrated by the powder flow contact frequency correlating with the final part thickness distribution. This approach provides a viable method to predict and optimize the uniformity of part thickness in rotational moulding, offering a significant computational efficiency advantage. The findings contribute valuable insights into the scaling of simulations for industrial applications, demonstrating that smaller-scale models can reliably predict real-world behaviours, thus enhancing the efficiency and accuracy of the moulding process. This study may contribute to the exploration of potentially more advanced and accurate simulation techniques in polymer moulding process, facilitating improved design and manufacturing processes in the rotational moulding industry.

Keywords: rotational moulding; discrete element method; powder flow simulation; robotic rotational moulding

Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2423

Thermal Dimensional Stability of PLA: Investigating the Role of Crystallinity and Annealing Temperature

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Abstract:

Polymeric materials are widely used across various industries due to their ease of processing and versatility, making them ideal candidates for replacing metal components. Bio-based polymers, such as poly(lactic acid) (PLA), offer sustainable alternatives to traditional plastics. PLA is particularly popular in additive manufacturing because of its high mechanical properties and ease of processing. However, its low thermal resistance can lead to dimensional stability issues in fabricated parts, potentially compromising the accuracy of pre-designed components. This study aims to investigate the thermal annealing effects on the thermal resistance and shrinkage of two types of PLA with different degrees of crystallinity. Injection-molded specimens of both PLA were produced and thermally annealed for 3 hours at 60°C, 90°C, and 120°C. Shrinkage, as well as mechanical and thermal properties, were examined to understand the effects of crystallinity and thermal annealing on both PLA types. Shrinkage was assessed by measuring the dimensions of impact specimens before and after thermal annealing. Results indicated that amorphous PLA exhibited lower thermal dimensional stability, with shrinkage increasing proportionally to the heat treatment temperature. In both PLA types, impact strength was higher in samples annealed at 90°C, although the results fell within the range of experimental deviation. Elongation at break decreased with higher temperatures, while the elastic modulus generally showed a slight increase. Differential Scanning Calorimetry (DSC) analysis revealed the evolution of crystallinity with heat treatment and its correlation with the mechanical and shrinkage results. The findings suggest that crystallinity can indeed influence thermal dimensional stability, as the crystalline regions can act as anchors that mitigate PLA shrinkage; and optimizing the crystallinity degree through controlled thermal annealing could be a key strategy in enhancing the dimensional stability and mechanical performance of PLA-based materials.

Keywords: poly(lactic acid) (PLA); thermal annealing; shrinkage; crystallinity degree.

Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2424

Heated uniaxial electromechanical tests to assess the deformability of functional conductive inks for In-Mold Electronics

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Abstract:

In-Mold Electronics (IME) enables the addition of functionality and the increase of complexity to the parts to be manufactured. Nevertheless, due to the complexity of integrating various technologies, numerous aspects remain to be explored in greater depth. One of them is regarding the deformability of inks used in the context of IME, since during the thermoforming process the electrical circuit may undergo substantial deformation, which directly impacts their performance. The aim of this work is to study the deformability and integrity of conductive prints through heated tensile uniaxial tests. A structure containing two ceramic heaters was coupled to the tensile test machine parallel to the specimen placement, and a data logging multimeter (OWON XDM1241) was connected to the sample's extremities and used to monitor and measure the electrical resistance. Tests were performed when the samples reached 155°C and 200°C (± 5°C), at a constant velocity of 20 mm/min. The printings were done at a semi-automatic screen printer, using commercially available polycarbonate substrates of two thicknesses (LEXAN™ 8A13E 250 microns and 500 microns, Sabic) and two conductive inks, one silver-based and the other carbon-based (DuPont ME614 and ME201, respectively). Measurements of the electrical resistance were taken before and during the tests, and morphological characterizations (line width and thickness) of the prints are drawn before and after the induced deformation. As anticipated, the results showed that silver paint exhibited significantly higher conductivity than carbon paint. Silver paint demonstrated a bigger resistance to deformation, on average up to 10 times less than carbon paint without exhibiting signs of breakage. Thicker sheets (e.g., 250 microns and 500 microns) exhibited higher allowable deformation values. The results revealed that sheet temperature did not have a significant influence on resistance variation when compared to other variables.

Keywords: Heated uniaxial electromechanical tests, In-Mold Electronics, deformability, functional conductive inks.

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Topic: Poster Presentation
Category: Abstract
Paper Number: P2439

Methodology for assessing the properties of materials produced by Fused Filament Fabrication (FFF) using CAE studies

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Abstract:

The use of Additive Manufacturing (AM) inserts to implement in conventional processes could lead to new design configurations of the same product. The production of parts with different designs using the same injection mould became a reality with the use of AM technologies. It is possible to produce filament for the FFF process using the same material that will be used in the injection moulding process instead to use commercial filaments using other grades of materials, which leads to a better compatibility at the interface between the two materials and to a better adhesion of the injected material with the insert. The only drawback is related to the knowledge or prediction of the mechanical behaviour of such products since de AM inserts could lead to the loss of some mechanical properties due to the process. Simulation of the mechanical properties of parts produced by Fused Filament Fabrication (FFF) can be a great help in the development of prototypes or inserts for hybrid processes. The aim of this study is to present a methodology for simulations to assess the mechanical properties of the AM inserts without being required the characterization of all the materials developed from materials used in conventional injection moulding. For that were produced specimens for mechanical characterization of different materials. The results of those tests were than compared with simulation results in ANSYS Mechanical software in order to verify if it is possible to find a relation between the injection moulding material and the specimens from AM.

Keywords: Additive Manufacturing, mechanical characterization, CAE simulations.

Acknowledgment: This work was carried out within the framework of the “Agendas para a Inovação Empresarial” [Project nº 49, acronym “INOV.AM”), supported by the RRP - Recovery and Resilience Plan and by the European Funds NextGeneration EU. http://www.recuperarportugal.gov.pt/.

Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2441

Design of improved bio-inspired devices for diagnosis and repair strategies in tissue engineering

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Abstract:

Additive Manufacturing (AM), 3D printing and bioprinting advancements in tissue/organ printing allow to improve the performances of bioinspired functional tissue-constructs, able to replicate and reproduce complex shapes and structures in a reliable manner thus mimicking native tissue, also identifying the suitable strategy for material-function combination, according to the natural host tissue or whole organs to be repaired. Multifunctional porous scaffolds with controlled functionalities have been properly designed and developed through the conversion of digital models to 3D objects by joining materials in a controllable and precise layer-by-layer fashion, adopting selected polymers or micro/nano-composite materials as well as post-processing functionalization strategies1 to promote the extracellular matrix analogue deposition, also tuning functional scaffold features for regeneration strategies. Novel concept 3D scaffolds with improved features and complex geometry for bone repair, cranioplasty2, cartilage substitution, as well as for neural and cardiac tissue engineering or inspired to the complex and hierarchical structure of intervertebral disc3 have been recently developed via 3D printing/bioprinting. On the other hand, novel concept diagnostic/prognostic tools for rapid clinical decision making have been recently obtained via 3D printing/bioprinting and combined with hydrogel-based materials as cell or drug/protein/gene delivery systems4 or as in vitro models for the study of cellular crosstalk between engineered tissues. Bioactive and antibacterial customized structures for prevention and treatment of neurological diseases represent a novel scenario, open to improvements and innovation. The dysbiotic microbial environment triggered by the pathogen releases proinflammatory factors into the periodontium, which cause chronic inflammation and ultimately result in the destruction of soft tissue support, gingival recession, bone resorption, and the loss of teeth. Infection mediated by gram positive and gram-negative oral bacteria, such as are Porphyromonas (P.) gingivalis, Aggregatibacter (A.) actinomycetemcomitans, Treponema (T.) denticola, and Fusobacterium (F.) nucleatum etc. appears to be potentially related to the pathogenesis of Alzheimer's Disease (AD), causing neuroinflammation and neurodegeneration. The combination of customized devices fabricated by additive manufacturing and in vitro models based on co-culture of MG63/SH-SY5Y cell lines embedded in different formulations of collagen and hyaluronic acid-based semi-IPNs offers the possibility to approach the study of crosstalk phenomena between engineered tissues for controlled delivery of cell-produced neuroprotective factors in experimental contexts of AD. The obtained data offers new perspectives for the optimization of hybrid medical devices capable of reducing the local inflammation and advanced periodontitis and, hence, the development of AD. A strong clinical impact in patients' management towards easier and standardized approaches for health operators will provide substantial contributions to the health care system sustainability. At the preoperative stage, the potential optimization of the most appropriate steps and models could improve the effectiveness of different planned surgeries, with running costs due to the high degree of automation and minimal sample manipulation.
Acknowledgement: The technical assistance of Dr. Stefania Zeppetelli and Mr. Rodolfo Morra is gratefully acknowledged. PRIN 2020WREYF2 – 3D Customized HYbrid MedicAl Devices for Alzheimer's disease-related Periodontitis Treatment - 3D CHYM ADAPT financial supported part of the proposed research.

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Keywords: hybrid structures; tissue repair strategies; design for additive manufacturing; AD-related periodontitis treatment

Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2447

Design and development of 3D multifunctional hybrid scaffolds for tissue repair

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Abstract:

INTRODUCTION

Tissue Engineering (TE) aims to repair tissue defects using 3D scaffolds, which resemble the extracellular matrix, sup-porting cell vitality and differentiation. In this context, "nonconventional" fabrication technologies such as Additive Manufacturing (AM) are crucial to design customized devices with complex shape and multifunctional features. Advanced devices with complex geometry for load-bearing applications in bone repair, as well as for cranioplasty, cartilage substitution or inspired to complex and hierarchical structure of intervertebral disc, as well as multifunctional structures for neural, and cardiac TE have been developed via 3D printing/bioprinting and combined with hydrogel-based materials as cell or drug/protein/gene delivery systems. The aim of the current research was to propose design strategies towards the development of hybrid additive manufactured scaffolds with enhanced mechanical, biological and functional proper-ties for tissue repair.

EXPERIMENTAL METHODS

Neat PCL scaffolds (10x10x3 mm^3) characterized by a 0°/90° laydown pattern were fabricated by processing poly(ε-caprolactone) (PCL, Mn = 45000, Sigma-Aldrich) pellets via Allevi 3 bioprinter, using a printing speed of 3mm/s, equipped with a nozzle with an inner diameter of 400 μm. A layer height of 300 μm and an infill distance of 1.6 mm were adopted. 3D PCL scaffolds were integrated with chitosan (Cn) solution (3% w/v in 1% acetic acid solution), followed by the dropwise addition of Na2HPO4 (125mg/ml). Hybrid structures with dual porosity were obtained after lyophilization process (-80°C, 24h) of the 3D PCL/Cn scaffolds. Swelling and degradation measurements were carried out after immersing dried chitosan scaffolds in distilled water or PBS at 37°C. At defined time points, swollen hydrogels were weighed after removal of excess of PBS whilst, for degradation study, scaffolds were frozen (−80°C) and lyophilized to evaluate the specific weight after defined incubation time. Compression, three-point bending, and Brazilian tests were performed to evaluate the mechanical behavior of the 3D hybrid structures. All the tests were carried out at a rate of 1 mm/min, using an Instron 5566 testing machine. On the other hand, viability and proliferation of bone-derived human osteosarcoma cells (MG 63) were evaluated by means of Alamar BlueTM assay, whilst the ALP activity was measured as an early osteogenic differentiation marker.

RESULTS AND DISCUSSION

Results from mechanical tests highlighted that the inclusion of an internal porous chitosan network did not substantially influence the mechanical behavior of the proposed hybrid structures, but it could be responsible for a stabilizing effect. From biological point of view, the inclusion of chitosan had a great impact on cell proliferation and ALP activity over culture time.

CONCLUSION

The current study may be considered as a first step of a future complex work with the aim of studying the effect of the inclusion of chitosan network in a 3D porous multifunctional structure obtained via AM technologies, also taking into account the possibility of adopting two different swelling and degradation rates in order to modulate drug/protein/gene delivery over time, thus tailoring the tissue regeneration process.

Keywords: Design for additive manufacturing; hybrid structure; tissue repair strategies

Acknowledgement: The technical assistance of Dr. Stefania Zeppetelli and Mr. Rodolfo Morra is gratefully acknowledged. PRIN 2020WREYF2 – 3D Customized HYbrid MedicAl Devices for Alzheimer's disease-related Periodontitis Treatment - 3D CHYM ADAPT financial supported part of the proposed research.

Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2448

Mechanical characterisation and fibre morphology analysis in ABS and short carbon fibre composites: influence of different polymer processing techniques

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Abstract:

Polymer composites have attracted considerable interest due to their potential to enhance mechanical properties of polymers or advanced applications. Yet, challenges exist including complex mechanical behaviour and poor affinity between reinforcement material and polymer matrix. This study investigates the influence of various processing methods on the mechanical properties of acrylonitrile butadiene styrene (ABS) reinforced with 15 wt% short carbon fibres (sCF), focusing mainly on fibre morphology. By analysing injection moulding (IM), fused filament fabrication (FFF) and compression moulding (CM), this research aims to elucidate the relationship between the processing method, fibre orientation and mechanical properties. Improved affinity is achieved through nitric acid surface treatment. Scanning electron and optical microscopy are used to analyse the morphology, revealing insights into void presence and fibre roughness, length, distribution and orientation. Additionally, mechanical properties are assessed through impact, tensile and flexural tests. Significant differences in morphology among ABS/sCF composites produced by different methods are revealed. Microscopy images show that in IM parts, fibres are highly aligned in the shear layer but exhibit a more varying orientation in the core, with minimal voids. FFF parts exhibit excellent sCF alignment but show voids between different layers, whereas CM parts display varying fibre orientations and small air inclusions. These differences notably affect the mechanical properties. Test bars produced via IM demonstrate superior stiffness, tensile strength and tensile strain at break, followed by FFF (which shows very high impact strength), while CM parts exhibit the least favourable properties, partly due to their isotropic nature and random sCF orientation. These outcomes can be immediately linked to the resulting morphologies. The findings of this work highlight the critical role of processing methods and fibre morphology in determining composite performance.

Keywords: polymer composite; processing techniques; fibre morphology; mechanical properties.

Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2449

Enhancing thermal conductivity of ABS and short carbon fibre composites: Influence of processing techniques on carbon fibre orientation

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Abstract:

Polymer composites play a significant role in the transition to a sustainable future due to their exceptional material properties. By adding fillers to a matrix, thermal properties can be improved, allowing for broader application of lightweight materials. This study focuses specifically on acrylonitrile butadiene styrene (ABS) in combination with 15 w% short carbon fibres (sCF), which form a composite with improved thermal conductivity. Although most research has focused on compression moulding, this study examines other relevant techniques including extrusion-fused filament fabrication (FFF) and injection moulding. To ensure superior material properties, the adhesion between the matrix and the fibre is investigated, by comparing the compatibility between the matrix and untreated fibres, and matrix and fibres that have undergone a surface treatment with nitric acid. Based on optical microscopy and SEM, it could observed that fewer air voids were visible in the pellet with the treated fibre. Consequently, the treated fibre showed significantly better adhesion to the matrix. The SEM images showed that the treated fibres did not have increased surface roughness. Therefore, the improvement is due to the formation of functional groups. Furthermore, the fibre length distribution of the untreated and treated fibre after compounding showed that the treated fibre underwent less fibre breakage then the untreated fibres, as a result of the improved adhesion protecting the fibres. The improvement in thermal conductivity measured by the Transient Plane Source (TPC) method, is mainly influenced by fibre orientation and not by fibre length, as the fibre length distributions for the three processing techniques did not show significant differences. In contrary to literature, compression moulding resulted in anisotropic properties due to high pressure and low temperature, which aligned the fibres and increased the in-plane thermal conductivity to 1.737 ± 0.045 W/(m·K) compared to the thermal conductivity of ABS (0.1818 ± 0.0004 W/(m·K)), while the through-plane conductivity decreased to 0.053 ± 0.007 W/(m·K) due to entrapped voids in the material. For single screw extrusion followed by FFF, the fibres were aligned in the flow direction due to the shear forces present, resulting in an increased thermal conductivity of 1.532 ± 0.018 W/(m·K). In the through-plane direction, a decrease of 0.166 ± 0.002 W/(m·K) was observed due to the weak adhesion between the layers. Finally, injection moulding showed the smallest increase in thermal conductivity in the in-plane direction, due to the less alignment of the fibres in the core layer, where shear is minimal. It should be noted that the in-plane thermal conductivity at the end of the 1A tensile test bar showed a greater increase, namely 1.126 ± 0.013 W/(m·K), whereas at the gate the in-plane thermal conductivity was 0.999 ± 0.003 W/(m·K). However, it shows the greatest in-crease in through-plane thermal conductivity, namely 0.199 ± 0.001 W/(m·K), which is more important for most applications such as a heat exchanger.

Keywords: ABS; sCF; HNO3 surface treatment; polymer processing; fibre length distribution; fibre morphology; thermal conductivity

Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2450

Enhancing Biodegradable Packaging: Comparative Analysis of HDPE/Starch-based Blends

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Abstract:

The widespread utilization of polymeric materials, particularly in the packaging industry, is driven by their excellent properties including lightweight and low cost (1,2). However, the environmental impact of these petroleum-based plastics, mostly polyolefins, necessitates a shift towards biodegradable alternatives. In this context, starch-based polymers rise as a promising alternative to traditional petroleum-based polymers in the food packaging sector (1–3). Starch offers the advantage of being inexpensive, renewable and biodegradable. It is however impossible to thermally process dry starch granules by itself, since the decomposition temperature of native starch is lower than its melting temperature (4). Nevertheless, when mixed with a gelatinizer and subjected to heat and shear, starch undergoes a destructurization, leading to a homogeneous melt known as thermoplastic starch (TPS) (3). Despite its poor mechanical properties, blending TPS with HDPE, and introducing compatibilizers, could improve its performance.

In the present work, blends of HDPE and starch are systematically compared. Starch will initially be applied in its native granule state and will be blended with HDPE, at concentrations of 2,5 – 5 – 10 wt% starch. Subsequently in a second approach, starch will first undergo gelatinization in a twin screw extruder utilizing glycerol as a plasticizing agent before blending it with HDPE in concentrations up to 50 wt%. In a final phase, a compatibilizer, ethylene vinyl alcohol (EVOH), will be introduced to enhance the compatibility within the HDPE/TPS blend. The morphological, thermal and mechanical characterization of the blends is assessed by scanning electron microscopy (SEM), differential scanning calorimetry (DSC), melt flow index (MFI), and tensile- and impact tests.

The results of the mechanical tests, tensile strength in particular, reveal that adding a compatibilizer is not enhancing the strength of the material as depicted by the tensile strength results in Figure 1. This can be explained by the SEM-images (Figure 2) that show a pronounced droplet morphology for the HDPE/TPS (+EVOH) blends, leading to a brittle material with low tensile strength, whereas blends with native starch show less but bigger droplets. Therefore it can be concluded that blends with native starch are favorable when the starch content is lower than 10wt%, taking in mind the processing steps and economical aspect. When >10wt% starch is required, HDPE/TPS are preferred since EVOH is not enhancing the properties to a great extent and represents an additional chemical input.

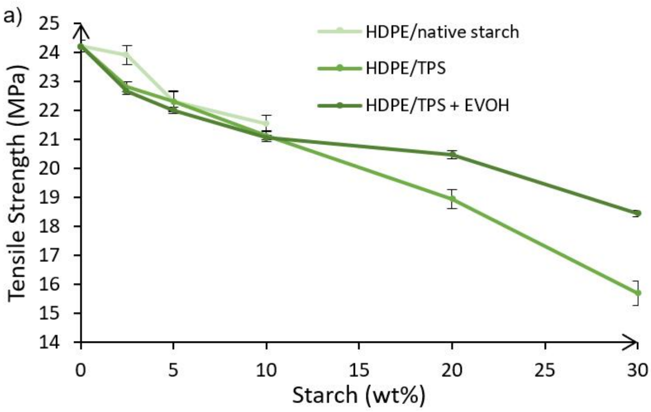

Figure 1. Tensile strength of HDPE/native starch, HDPE/TPS and HDPE/TPS + EVOH.

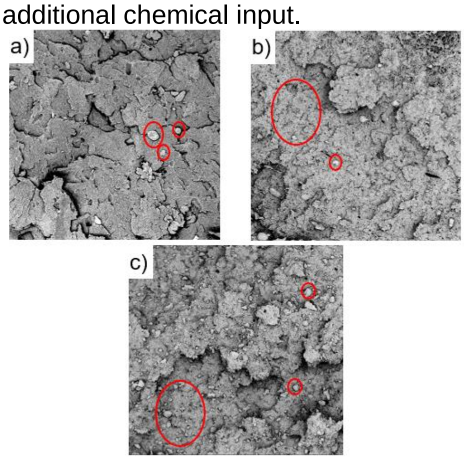

Figure 2. SEM images (250x magnification) of a) HDPE/native starch b) HDPE/TPS and c) HDPE/TPS + EVOH with 10 wt% starch in each

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Keywords: Biodegradable polymers; Thermoplastic starch; High Density Polyethylene

Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2451

Thermo-mechanical degradation of recycled polyesters processed with different amounts of water content

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Abstract:

In recent decades, the use of plastics has surged due to their low cost, durability, and versatility, making them integral to sectors like construction, consumer goods, and electronics [1], [2]. In 2023, global plastics production reached 400.3 Mt, with 14% in Europe [3]. However, environmental concerns are prompting a shift from a linear economy to a circular one that emphasizes reducing, recycling, and recovering plastics.
Polyesters, particularly oil-based polyethylene terephthalate (PET), are popular choices for mechanical recycling due to their favorable properties and high recyclability [4]. PET Items, in particular bottles and trays, have a high recycling rate in Europe, with about 49% collected and sorted for recycling. The recycling suitability of post-consumer PET flakes is significantly influenced by the level and type of contaminants, which include acids, foreign polymers (e.g. PVC), water, coloring contaminants, and other organic and inorganic substances [5], [6]. These contaminants affect the degradation mechanism during reprocessing, creating a complex interaction between temperature variations, mechanical forces, molar mass, and viscosity changes. Additionally, increased residence times lead to more volatile odorous components and reduced product quality, e.g. discoloration. Although lab-scale requirements for post-consumer PET flakes are well defined, there is a lack of specific data for larger industrial-scale implementation, which may require different requirements due to variations in mechanical design.

In this work, PET with varying moisture content is processed up to three times using a APV twin screw extruder. To investigate the effects of hydrolytic degradation during PET (re)processing, experimental analysis such as MFI, GPC and FTIR are employed to gain deeper insights into the degradation process. By altering process parameters (e.g. barrel temperature and screw speed) a broader understating of degradation phenomena can be achieved across a wider range of experiments. The goal of the current study is to combine both an experimental and modeling approach to bridge the molecular and macroscopic properties, enabling a better understanding and the possibility to further fine-tune the process.

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Keywords: extrusion; PET; hydrolytic degradation; mechanical recycling; contaminants

Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2452

Tribological Comparison of Injection-molded and 3D-printed Parts of Polyethylene Terephthalate Glycol

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Abstract:

Polymers are becoming increasingly popular today due to their numerous need-based applications. The most significant polymer processing technologies include injection molding and 3D printing. Several tribological research studies have been conducted on injection-molded and 3D-printed parts individually; however, research work on comparing the tribological properties of injection-molded and 3D-printed components is scarce. This research aims to compare the tribological behavior of three different grades of Polyethylene Terephthalate Glycol (PETg) processed through injection molding and 3D printing (fused filament fabrication) processes. The manufactured samples are tested for their wear behavior using a pin-on-disc abrasion tester under fixed testing conditions. It is concluded from the abrasion tests that the medium-viscosity injection-molded PETg samples have the best anti-wear properties among the selected grades of PETg and can be used for products more prone to wear phenomena.

Keywords: Injection Molding, 3D Printing, Polyethylene Terephthalate Glycol, Specific Wear Rate.

Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2453

Phan–Thien–Tanner model applied in CFD 3D simulation of slit die simulations of different AM materials

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Abstract

Polymer processing has traditionally relied on trial and error to refine process parameters and enhance the quality of the final product. However, this approach has become outdated with the advent of CFD simulations that utilize rheological models[1]. Additive manufacturing is intensively applying such simulations. A significant challenge in this area involves the polymer melt's tendency to swell at the die exit during printing, a phenomenon attributed to instabilities in the processing phase. More recently, nonlinear differential models were applied for CFD simulations of the polymer melt. The Phan–Thien–Tanner (PTT)[2] model in its exponential form, has proven multiple times to give the best fit for non-linear rheological properties of polymer melts[3]. In this work, we have selected three materials: Polypropylene (PP), polyethylene terephthalate glycol (PETG) and Polylactic acid (PLA). The fit with the PTT model was employed for the data series depicting its validity. All the materials were compared based on the rheological properties. Then 3D simulation of the material through a slit die were carried on and the swelling of the material was compared. Moreover, in the case of PETG, the model was employed for the evaluation of the effect of the recycled material on the swelling behavior. The 3D simulation allowed us to see the effect on both the representative length of the slit die.

Keywords: CFD simulation, Phan–Thien–Tanner model, Swelling, Additive manufacturing, Recycling.

Acknowledgment: This work is funded by Vlaio: GreenAM project.

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Topic: Poster Presentation
Category: Extended Abstract
Paper Number: P2455

Molecular Design, Material Performance And The Application Potential In Polymer Network Research

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Abstract:

Polymer networks play an indispensable role in advancing next-generation materials. The design of such large-scale chemical entities is challenging, primarily hindered by the limited comprehension of the effect of reaction conditions on the final macroscopic properties of polymer gels and their product performance due to a lack of proper characterization tools for such complex topologies. Our research group has developed a combined kinetic Monte Carlo and molecular dynamics tool that accounts for kinetics, thermodynamics, and topological features of the formed polymeric networks. By employing this in silico-based characterization tool, we can thoroughly examine the structural evolution of individual macromolecules/segments throughout network formation. This facilitates the fundamental insight into structure-property relationships, bridging the molecular and material scales, and enables the development of synthesis protocols toward maximal material performance. In this work, experimental studies into the synthesis, material characterization, and practical application level of organosilica networks demonstrate the high validation potential of this advanced tool. One notable application is the sol-gel-based synthesis of organosilica networks for electrospinning highly resistant filtration membranes. These membranes show promise in various applications, including gravity-driven separation of heterogeneous azeotropes and ion-exchange processes.

Keywords: Polymer networks; Silica nanofibers; Properties tunning; Modelling and Simulation

Topic: Poster Presentation
Category: Abstract
Paper Number: P2464

Development of Simulation Models for the Optimisation of Type IV Hydrogen Tanks

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Abstract:

Within measures to address climate change and the drive for decarbonisation, renewable hydrogen is seen as the potential fuel of the future. Whilst much research is focussed on how to generate hydrogen, the diversity of potential end uses for the gas require means to capture and deliver it safely in both gaseous and liquid forms. Therefore, the safe and economic storage of hydrogen remains a key issue for its large-scale deployment, and this has spurred researchers to innovate new storage solutions. Most designs are type IV tanks meaning that they are manufactured from a polymer liner that is reinforced with multiple layers of filament-wound polymer composite. To be commercially viable (low cost and lightweight) and safe, such vessels must be designed to store hydrogen gas at pressures above 350 bar. In this work models have been developed to enable the simulation of type IV hydrogen storage tanks with the aim of optimising the design and manufactured structure of prototype tanks. These have been developed with the FE simulation software ABAQUS providing simulated stresses and displacement plots for various loading conditions using progressive failure analysis models. The developed FE simulation model provides axial and radial displacement (see **Fout! Verwijzingsbron niet gevonden.**) during charging and discharging of hydrogen. It has enabled evaluation of the types of polymers used for the liner and their combination with varying thicknesses of composite reinforcement. The work has also examined the design of the polymer liner and its integration with metal bosses of different designs. In this analysis simulation results have been compared to separately obtained experimental measurements of rotationally moulded of liners containing a range of integrated metallic bosses. These involved designs made from different grades of polyethylene and nylon 6 and with isotensoid and hemispherical ends.

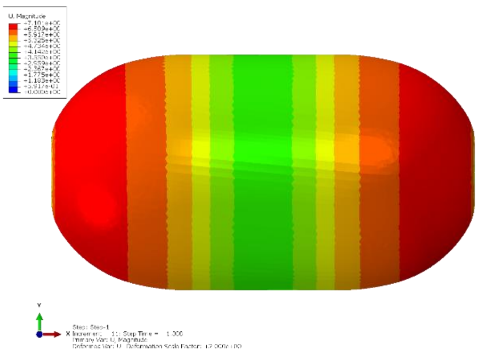

Fig 1 – Displacement Plot of Composite Fibre Layer

Keywords: hydrogen; type IV tanks; pressurized vessels, simulation, composite winding, green energy.

Topic: Poster Presentation
Category: Abstract
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Effect of multiflow vibration injection molding on the filler dispersion and thermal conductivity of polyethylene composites

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Abstract:

Thermoplastic composites are emerging as promising alternatives for thermal management application, especially in the development of next-generation electronics and heat exchangers. These materials offer several advantages over traditional metals, including lower cost, reduced weight, and superior corrosion resistance. However, their utilization depends on the possibility to improve their thermal conductivity (TC). Achieving high TC in thermoplastic composites involves careful design of the material, such as selecting appropriate filler types and shapes, and optimizing processing parameters like dispersion quality and mixing. Although much research has already been done on the thermal conductivity of thermoplastic composites, the majority of it is focused on the less economically relevant compression molding, while injection molding remain less researched. Injection molding is a versatile, non-continuous processing technique used for making products of different shapes and sizes. During the processing, molten polymer or composite is pushed into a mold cavity. The flow causes orientation of the fillers present in the polymer matrix, resulting in a material with anisotropic properties. More specifically, a skin-core structure will be visible in the product, where filler will be strongly aligned with the flow direction near the mold walls, while the center will show more random filler alignment, or alignment resembling the flow front. This anisotropic behavior influences thermal conductivity and should be considered when designing the composite material.

The aim of this research is to analyse the effect of multiflow vibration injection molding (MFVIM) on the filler dispersion and thermal conductivity of polyethylene composites containing multiple fillers. A high-density polyethylene (HDPE) matrix is considered, doped with 1.0 m% carbon nanotubes (CNT) in combination with three fillers of varying shapes and sizes, i.e., aluminum oxide (Al2O3; sphere-shaped), graphite (G; platelet-shape) and expanded graphite (EG; platelet-shape). Conventional injection molding (CIM) is compared to MFVIM in which three and five melt flows are introduced, each for three different filler combinations. Scanning electron microscopy (SEM) is used to observe the orientation and dispersion of the fillers in the produced parts and thermal conductivity measurements are done in the in-plane (IP) and through-plane (TP) direction. SEM images of these injection-molded samples revealed clear differences between the CIM and MFVIM with three and five melt flows. For the TC measurements, the IP conductivity was much higher than the TP conductivity due to orienting of the fillers in the direction of the flow during processing. Differences in TC could also be distinguished between the CIM and MFVIM, as the IP TC showed an increase up to 37% when five melt flows were introduced during vibration injection molding compared to conventional injection molding.

Keywords: thermal conductivity; hybrid filler composite; multiflow vibration injection molding; polymer composite

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Increased impact toughness of mass polymerized ABS by tuning polymer orientation via vibration injection moulding

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Abstract:

In many sectors, stretching from house hold appliances to the automotive industry, acrylonitrile butadiene styrene (ABS) is applied for its promising material properties. More recent developments in the industrial production process of this polymer have provided improved stability of the raw material by using a continuous polymerization process, called mass polymerization. The ABS polymer resulting from this process, named mABS, is however slightly different in morphological characteristics as it rather mimics high impact polystyrene (HIPS) than the more conventional used emulsion polymerized ABS (eABS). These morphological characteristics make mABS more prone to processing related deviations in part performance and final product morphology. Hence, this research covers the effect of flow induced orientation on impact performance of mABS parts. To emphasize the effect of orientation, parts were produced using regular injection moulding and compared to specimens made by the novel method of vibration injection moulding, which applies a much higher amount of shear during processing and thus increased orientation within the final product.
Impact specimens were cut from platelet samples in the parallel and perpendicular direction respective to the flow path. Differences in morphological orientation of the rubber phase were determined via scanning electron microscopy (SEM) imaging. A distinct layered structure, providing increased orientation, was observed for the vibration injection moulded samples. This higher orientation caused a higher resistance against impact deformation applied in the perpendicular direction. For impact applied parallel to the oriented rubber phase however, no difference for increased orientation was established. This research could therefore draw similar conclusions as found in research covering performance of HIPS. It can thus be concluded that a higher degree of orientation within mABS parts can positively contribute to part performance, depending on the direction of deformation.
Comparing mABS to the more conventional eABS, it should be stressed that anisotropy after processing mABS is indeed high. This might cause altered product performance upon altering the used ABS type without considering process adaptations.

Keywords: mass polymerized acrylonitrile butadiene styrene; vibration injection moulding; polymer orientation, impact toughness

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