

Polymer Engineering and Science at Montanuniversitaet Leoben



PPE19 - Polymer Process Engineering International conference



30th Anniversary of the Polymer IRC

150th Anniversary of the IoM3



Montanuniversitaet Leoben congratulates!



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Post processing of polymeric cranial implants produced by material extrusion based additive manufacturing (FFF)

July 9th, 2019

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Joamin Gonzalez-Gutierrez, Sandra Pettersmann, Margit Pichelmayer, Gord von Campe

- **Introduction**
- **Methodology**
- **Results**
- **Conclusions**



INTRODUCTION

- **After traumata, lesions of the bones and necroses due to radiation**
- **Mostly for reconstructive implants**
- **Substitution of bone**



Stryker iD™ Customized Cranial Implants, <https://www.strykerneurotechnology.com/stryker-id-customized-cranial-implants>, 20170522

- **High thermal conductivity (metals)**
 - **Patient discomfort when changing temperature**
- **Radiation intransparency (metals)**
 - **Patient cannot go through radiotherapy**
- **Stronger than bone**
 - **Implant survives accident but the surrounding bone gets more damage**
- **Hard to rework**
 - **If the implant does not fit -> a lot of problems for the surgeons**
- **Clinic extern produced**
 - **Delivery time minimum 1 week**
- **2nd operation**

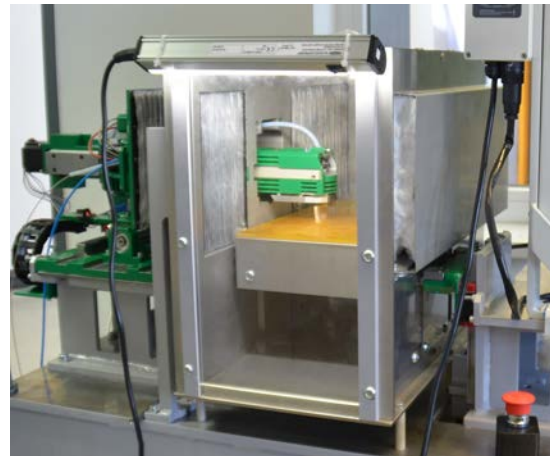
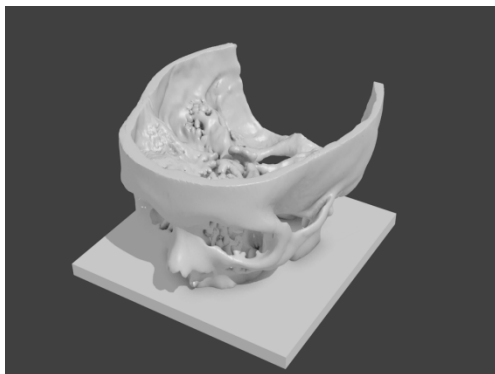
- Additive manufacturing allows part customization
- Economic production of small quantities
- Particularly important for orthopedic implants
 → Patient specific
- Within 1 operation



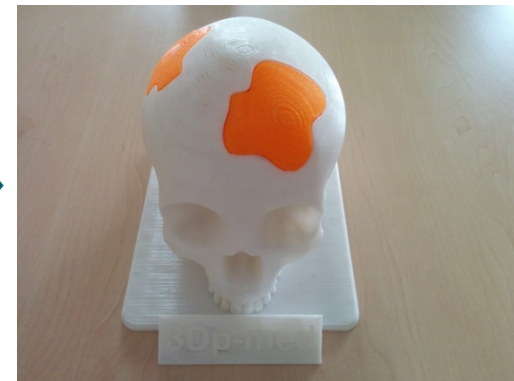
Choose material



Design implant



Put implant in place



Fabricate implant in hospital

- **Low thermal conductivity**
- **Radiation transparency**
- **Strength comparable to bone**
- **Can be biocompatible**
- **Can be shaped in compact, safe**
- **Can be easily reworked with heat**
- **ISSUE: Which polymer/s?**





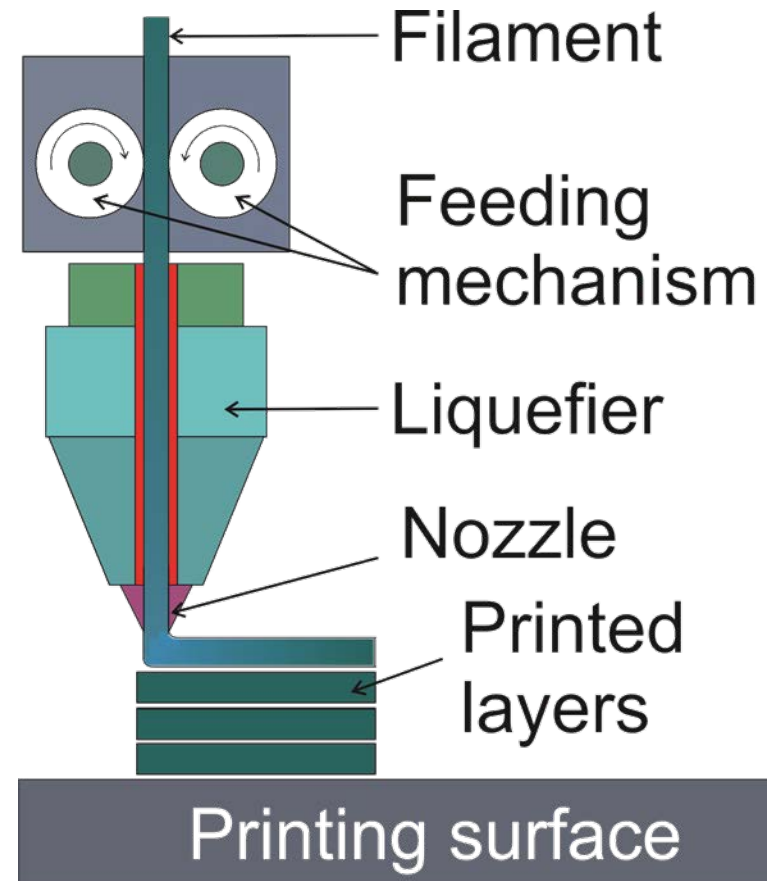
METHODOLOGY

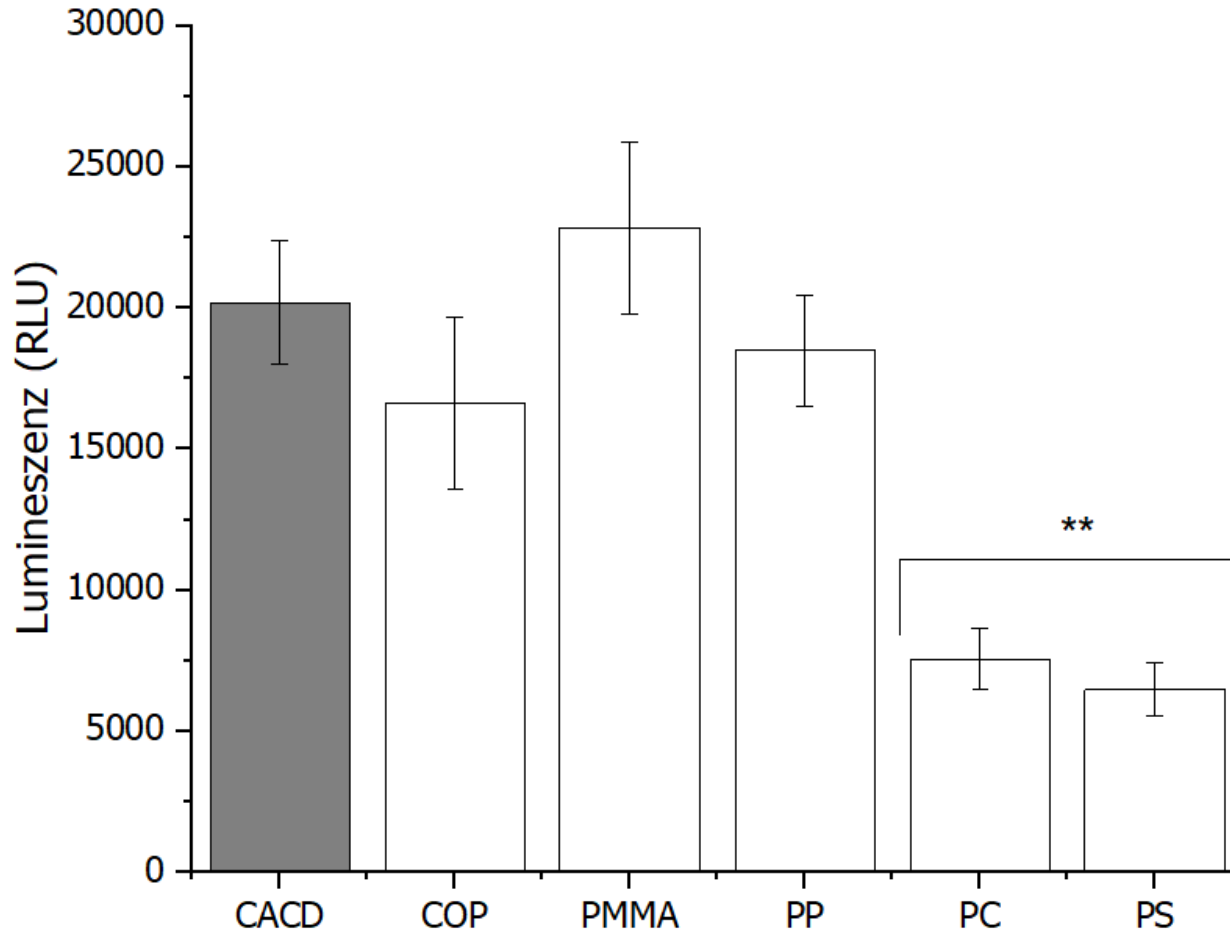
Flexibility for spooling

Transfer of force
(strength, no buckling)

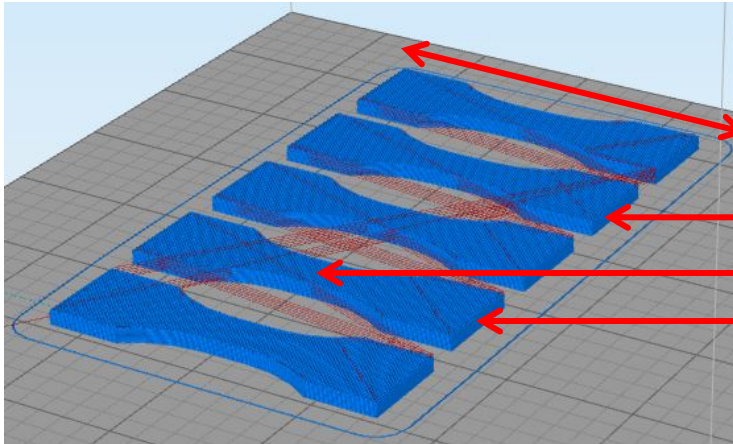
Thermoplastic extrusion
(flows & solidifies)

Adhesion and bonding to
printing surface and other layers





■ Printing of specimens (Modified ISO 527 1A)



$L = 7 \text{ cm}$
 $\text{Max. } W = 2 \text{ cm}$
 $\text{Min. } W = 1 \text{ cm}$
 $T = 0.3 \text{ cm}$



■ Testing at high speed

- Drop tower
- High speed camera
- Strain by Digital Image Correlation
- Rate: 1000 mm/s
- Standard room conditions



▪ **Criteria**

- Thermoplastics to process by FFF
- Low processing temperature (below 300 °C)
- Mechanical properties
- Medical grade (FDA approved)
- Good cell properties

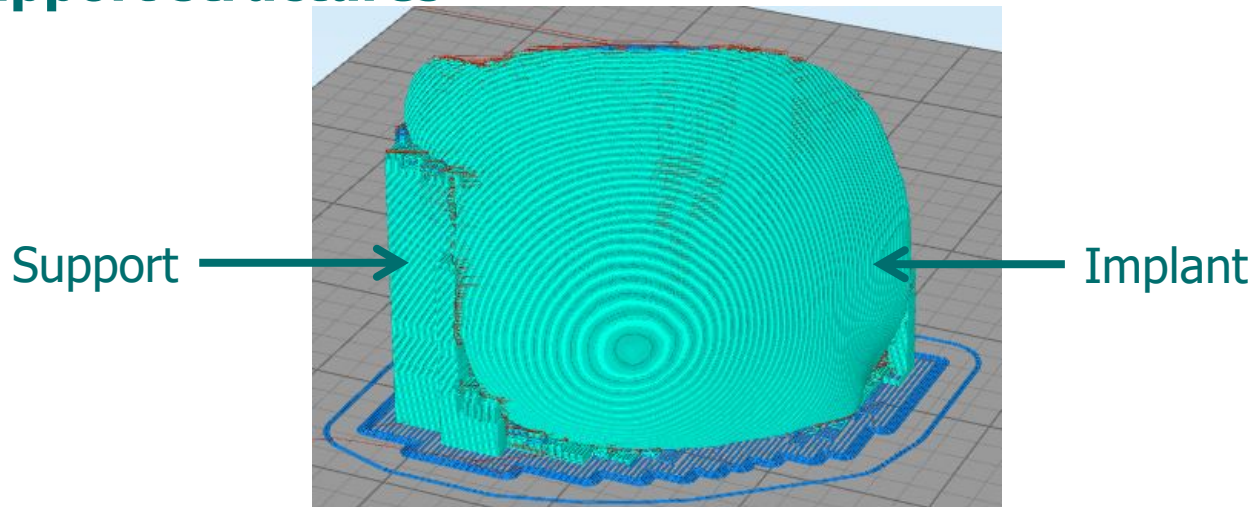
▪ **Polymers selected**

- Polyethylene terephthalate with glycol (PETG)
- Polypropylene (PP)
- Polyvinylidene fluoride copolymer (PVDF)
- Polymethyl methacrylate (PMMA)

- **STL file**



- **Adding support structures**



▪ Hage 3Dp A2

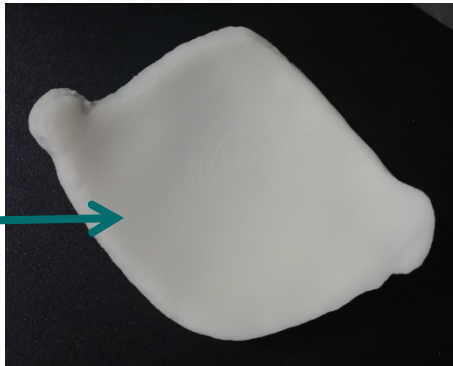
- PET-G (HD Glass clear: Form Futura)
- PVDF-C (White natural: 3Dogg.com)
- PMMA (Natural: Herz Germany)



▪ Wanhao duplicator

- PP (Filament self made) → needs PP building platform

Printed
implant



PP Plate



■ Criteria

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But do the PHYSICIANS like our materials?

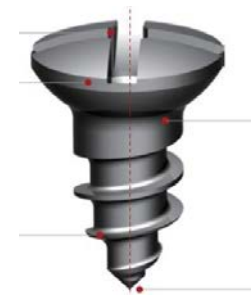
Medical doctors tried their hand tools

- Tiger wool grinding wheel
- Soft plastic polishing bur
- Double-barreled cross-cut bur
- Rubber polisher
- Diamond polisher
- Round bur
- Acrylic polisher-ACR



Two RPMs

- 15 000
- 40 000
- Measure implant temperature

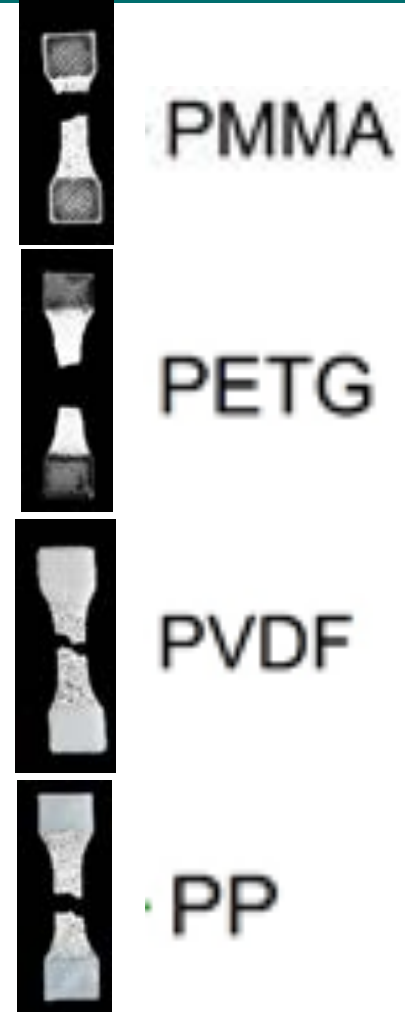
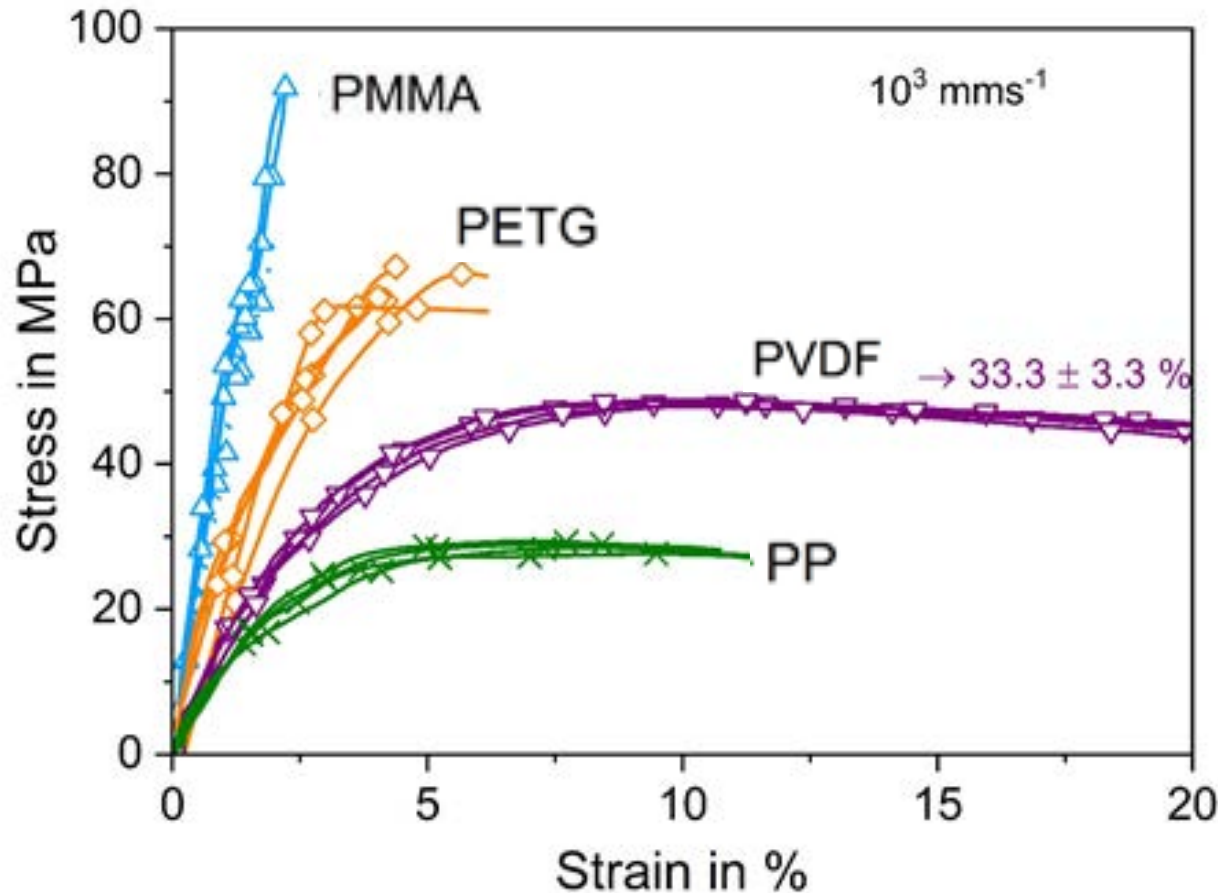


Positioning of screws

www.depuysynthes.com/binary/org/DPY_SYN/Products/Images/CMF/J30889_2_MATRIXNEURO_STERIKIT.png, 20190707
www.alibab.com, 20190707



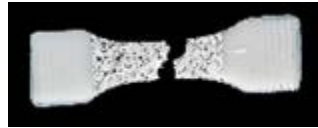
RESULTS



- **At high speed (1000 mm/s) all fail brittle**
 - PVDF has still a very large strain (33%) before breaking
 - Maybe better for impact resistance

- **Based on their experience with different materials related to implants and bones, physicians gave the following ranking:**

1. PVDF



Strong and more ductile

2. PETG



Stronger and still ductile

3. PP



Weaker and still ductile

4. PMMA

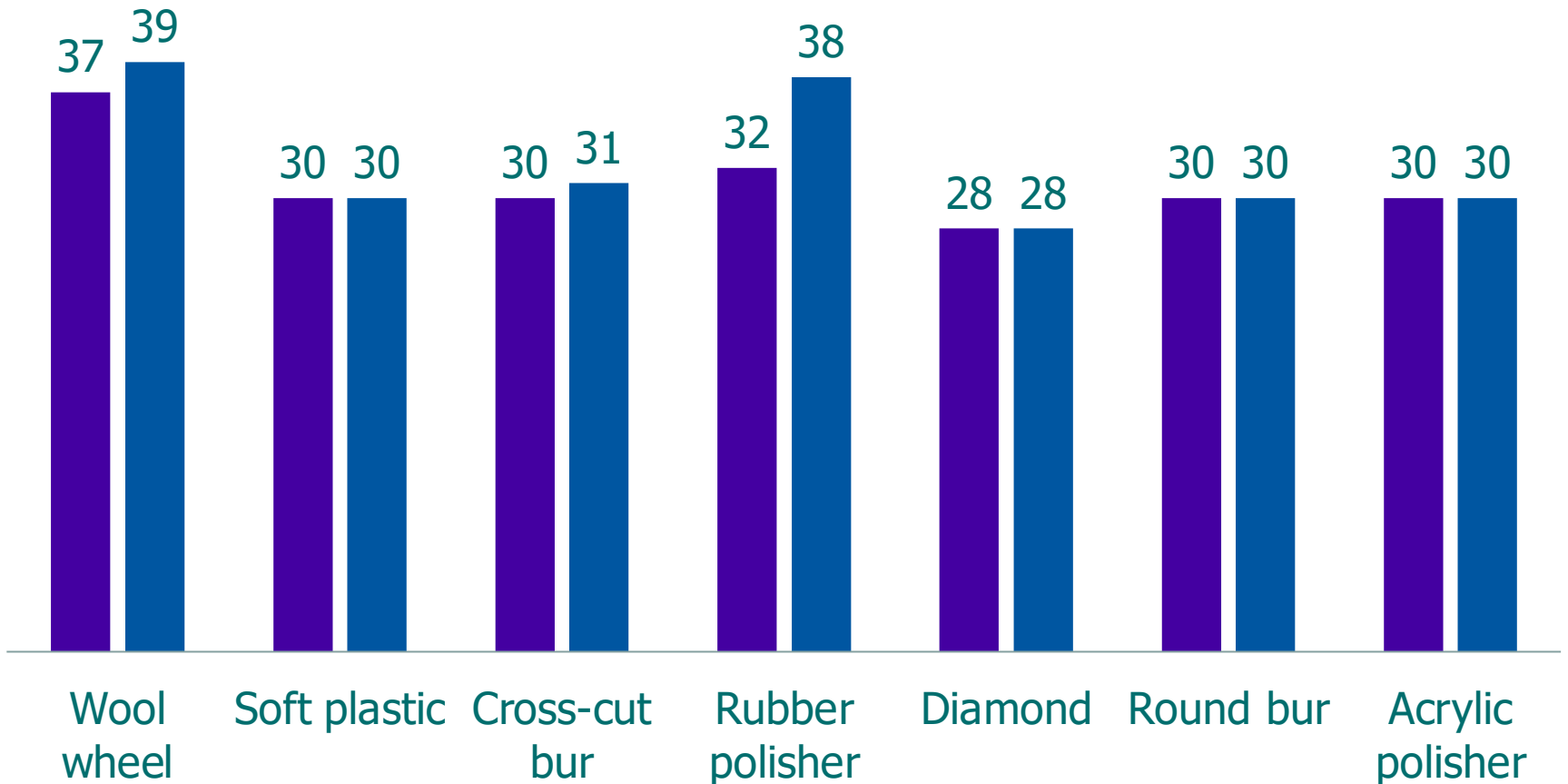


Strongest and very brittle

RPM	15000	40000	15000	40000	15000	40000	15000	40000
Material	PETG	PETG	PP	PP	PVDF	PVDF	PMMA	PMMA
Tiger wool grinding wheel	dusty, Super smooth surface, good to remove small defects	More dusty, super smooth surface	Works well	Smears	Super good	Super good, but fine dust (red, from the grinding wheel)	Sticks to surface	Sticks to surface
Soft plastic polishing bur	A lot of dust	A lot of dust	Smears and leaves threads	Smears and leaves threads	Good, but forms threads	Good	Very smooth	Very smooth

Temperature of PET-G Implant in °C

■ 15000 rpm ■ 40000 rpm



- **Maximum temperature 49°C**

- PMMA
- 40000 rpm
- Rubber polisher

- **Minimum temperature 28 °C**

- PMMA, PET-G, PVDF
- 15000 & 40000 rpm
- Diamond polisher

All implant temperatures remain well below melting (T_m) or glass transition (T_g) temperatures of all polymers

No risk of deforming implants due to heat

BEST

- **PVDF has the best performance with all polishing tools**
- **A screw still rotates in PVDF, but it does not come out**

2nd BEST

- **PMMA can be polished with many tools**
- **A screw can be fixed in PMMA**
- **Smells when hot due to friction**



CONCLUSIONS

- **FFF can be used to produce cranial implants & there are many materials available**
- **Material pre-selection done here**
 - High speed mechanical test & post-implantation stability trials
- **Using these criteria: PVD is like a good candidate**
 - Not so stiff and retains some elasticity after failure even at high rates
 - Good sensorial evaluation (perception)
 - Can be post-processed with many hand tools available at hospitals
 - Screw mechanism redesigned so it stays fixed in place
 - Implantation temperature between 46 and 28 °C
- **Future tests**
 - Cytotoxicity
 - Impact properties (Charpy, drop impact, etc.)
 - Effect of water & sterilization on mechanical properties

Who are your customers?

■ Co-authors

- Joamin Gonzalez-Gutierrez
- Sandra Pettersmann
- Margit Pichelmayer
- Gord von Campe



Medical University of Graz

■ Funding agencies

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THANK YOU VERY MUCH FOR YOUR ATTENTION

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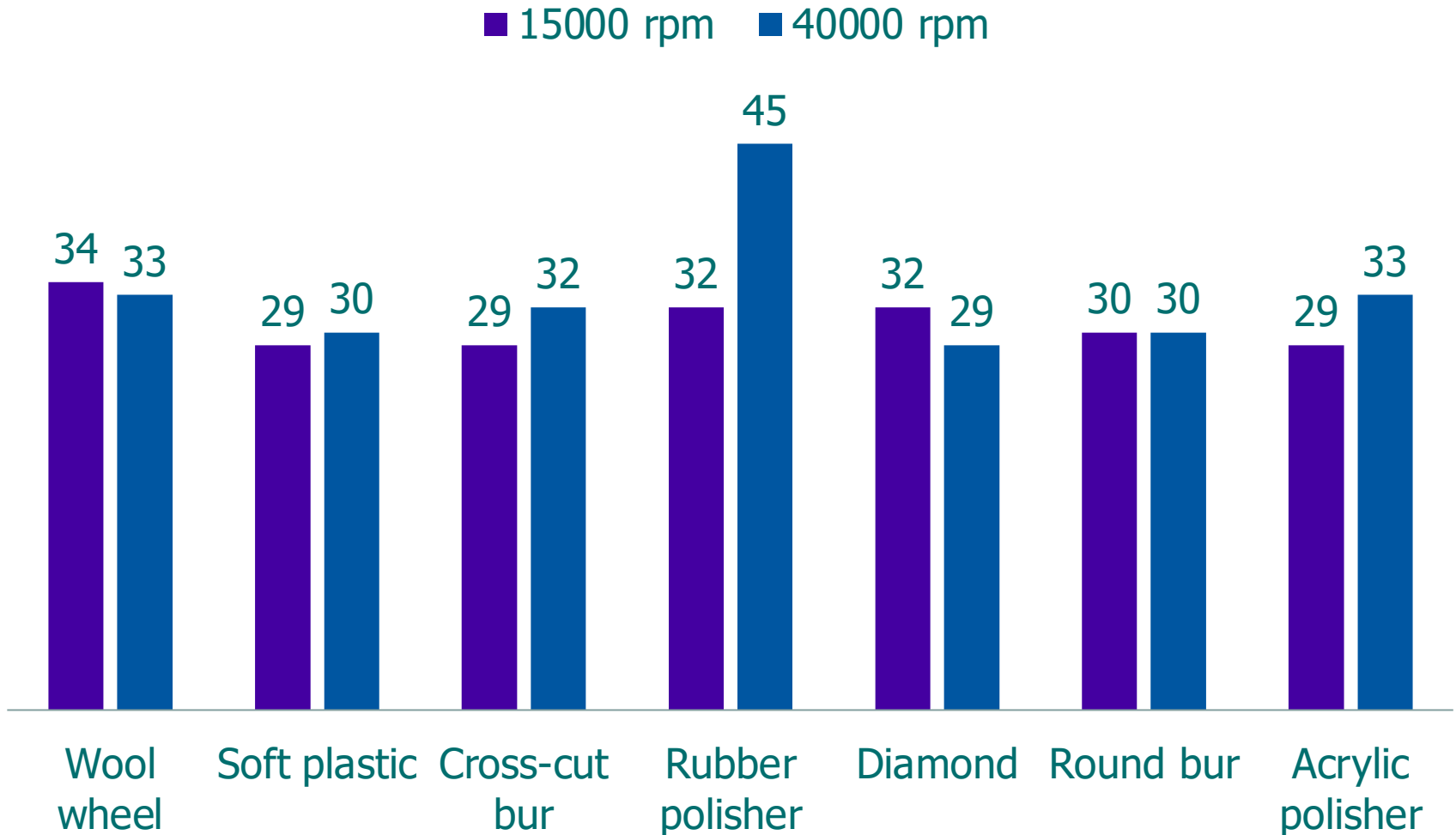
Montanuniversität Leoben, Department Polymer Engineering and Science
Otto Glöckel-Straße 2, 8700 Leoben, Austria

RPM	15000	40000	15000	40000	15000	40000	15000	40000
Material	PETG	PETG	PP	PP	PVDF	PVDF	PMMA	PMMA
Double-barreled cross-cut bur	Scrapping not so fine dust	More dust than at lower RPM	Smears and leaves threads	Smears and leaves threads	Fraying	Fraying	Good, small grooves	Better than at lower RPM
Rubber polisher	Smears	Gets hot, smears more than at lower RPM	Smears, but if you clean it's smooth	It's slightly better than at lower RPM	Good, but attrition happens	Good	Melts	Smooth, but gets hot

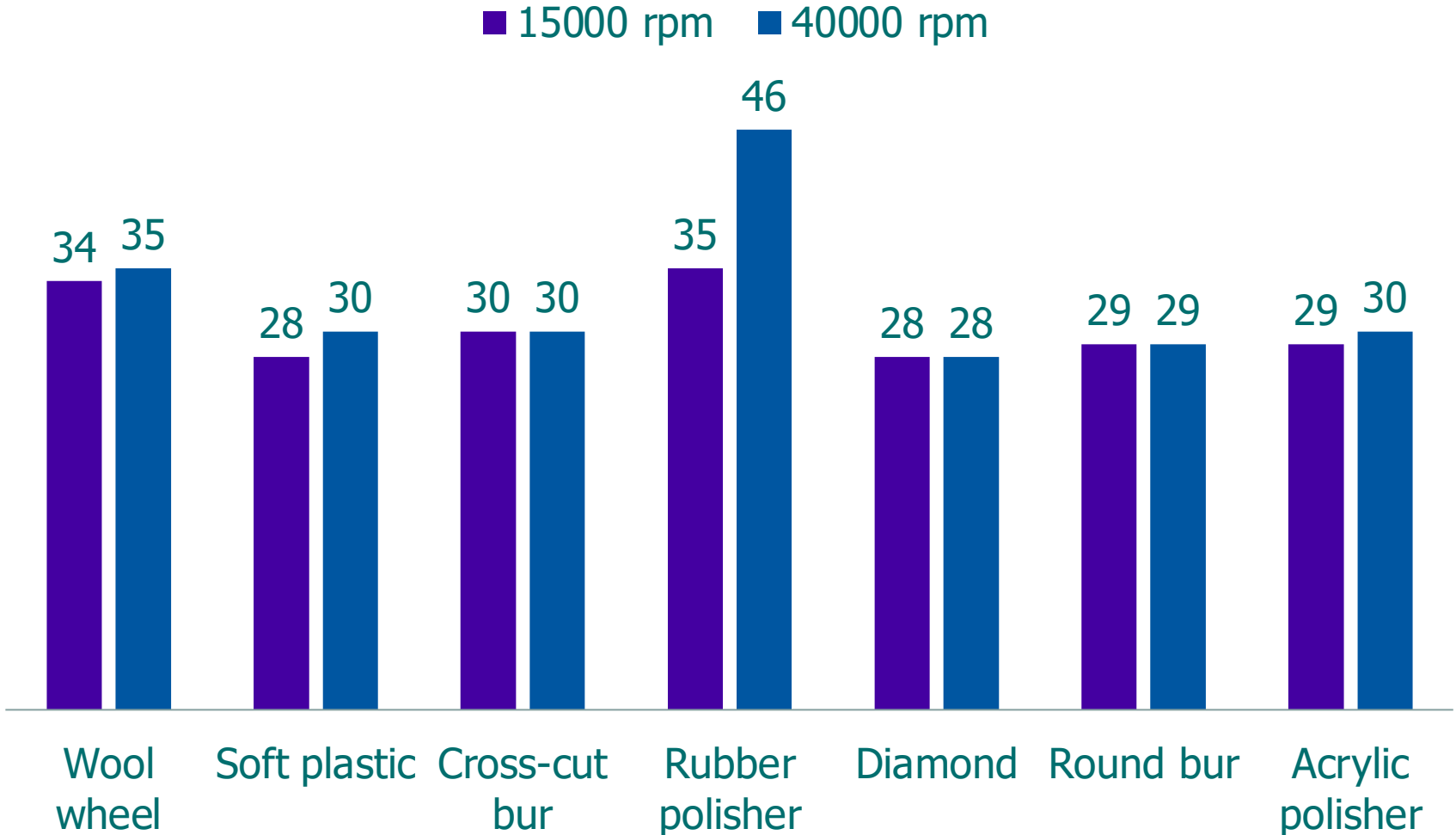
RPM	15000	40000	15000	40000	15000	40000	15000	40000
Material	PETG	PETG	PP	PP	PVDF	PVDF	PMMA	PMMA
Diamond polisher	Wears less than the bur	Starts to fringe	Melts and smears	Melts	Frays more	Frays a bit less	Works well	Works better, but pulls diamond into material
Round bur	Works good, no fringes	Works better than at lower RPM	Frays	Smears	Frays	Frays	Works well	Works well

RPM	15000	40000	15000	40000	15000	40000	15000	40000
Material	PETG	PETG	PP	PP	PVDF	PVDF	PMMA	PMMA
Acrylic polisher-ACR	Produces coarse chips, scrapes more	Very fine dust develops	Smears	Smears	Frays	Frays, but finer	Wears well	Works well, but flying chips are hot
Surface smoothness	Wool wheel smooths the entire surface well		Color of wool wheel stays at surface after polishing		Wool wheel smooths entire surface well		Color of wool wheel remains at surface after polishing	
Screw placing	Screw can be placed		Screw rotates & it's not fixed		Screw rotates but it does not come out		Screw holds, no over-rotation	
Special	-----		-----		-----		Strong smell after polishing due to heat	

Temperature of PP Implant in °C



Temperature of PVDF Implant in °C



Temperature of PMMA Implant in °C

■ 15000 rpm ■ 40000 rpm

