Production of zirconia pieces for dental applications by subtractive vs additive manufacturing: a comparative study

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1. Objective

✓ Validation of an additive manufacturing technique (robocasting) to produce reliable zirconia dental structures, comparing several properties of samples produced by both additive manufacturing (AM) and subtractive manufacturing (SM)

Why zirconia?

Main properties

- Modulus of elasticity: 100-250 GPa
- Flexural strength: 177-1000 MPa
- Fracture toughness: 1-8 MPa.m ^{½}
- Tensile strength: 115-711 MPa
- Hardness: 1250-1300 HV

Applications

- Implants
- Orthodontic brackets
- Abutments
- Copings
- Bridges
- Crowns

Advantages

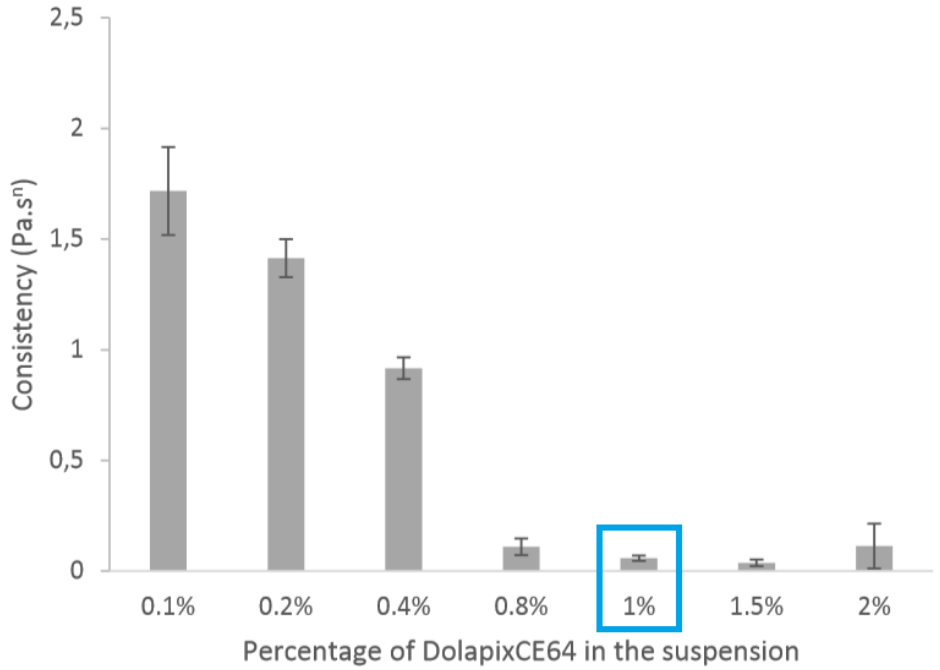
- Exceptional mechanical properties
- Ease of machining in the pre-sintering stage through CAD/CAM
- Biocompatible with the tissues in the oral cavity

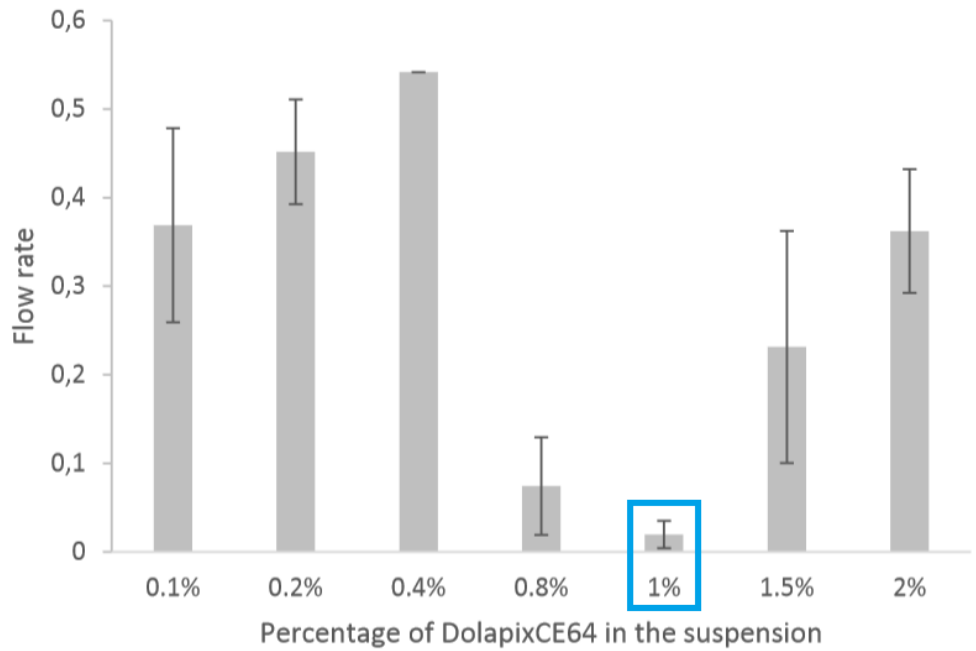
2. Pastes optimization

- Production of pastes with different compositions
- Rheologic study

Considered parameters:

2.1 Effect of the dispersant content → **Minimum values of consistency and flow rate**

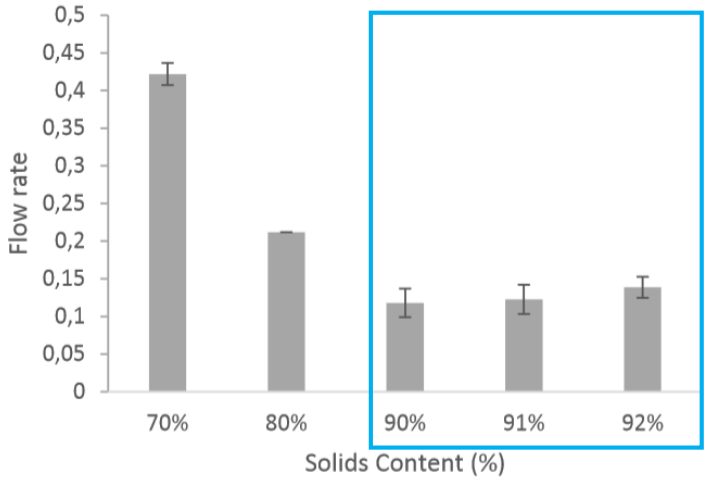


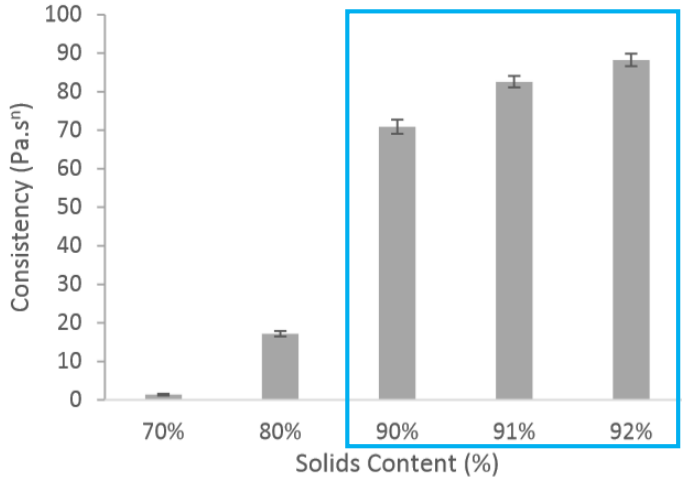


2. Pastes optimization

2.2 Effect of the solids content

Lowest flow rate and higher consistency





2.3 Effect of the preparation methodology

Heterogeneos paste resulting from directly mixing 90% solids

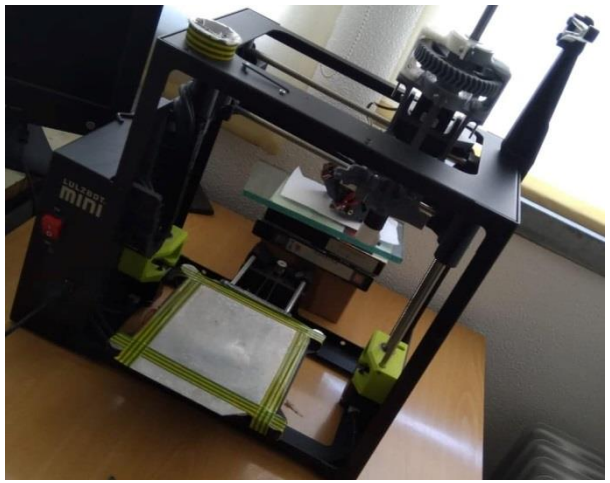
Homogeneous paste based on the evaporation of water

2. Pastes optimization

Composition of the chosen paste to produce zirconia pieces

	Composition		
Paste	Zirconia (60 wt% solids)	evaporation →	92 wt% solids
	Dolapix CE64 (1% of the solids content)		
	DD water		

→ Samples with **92% solids** are the most promising, concerning **density and porosity** when compared to commercial zirconia samples



2. Pastes optimization

Samples produced by our project partners

Samples obtained by milling of commercial yttria-stabilized zirconia blocks

Yttria (3% mol)-stabilized zirconia pieces

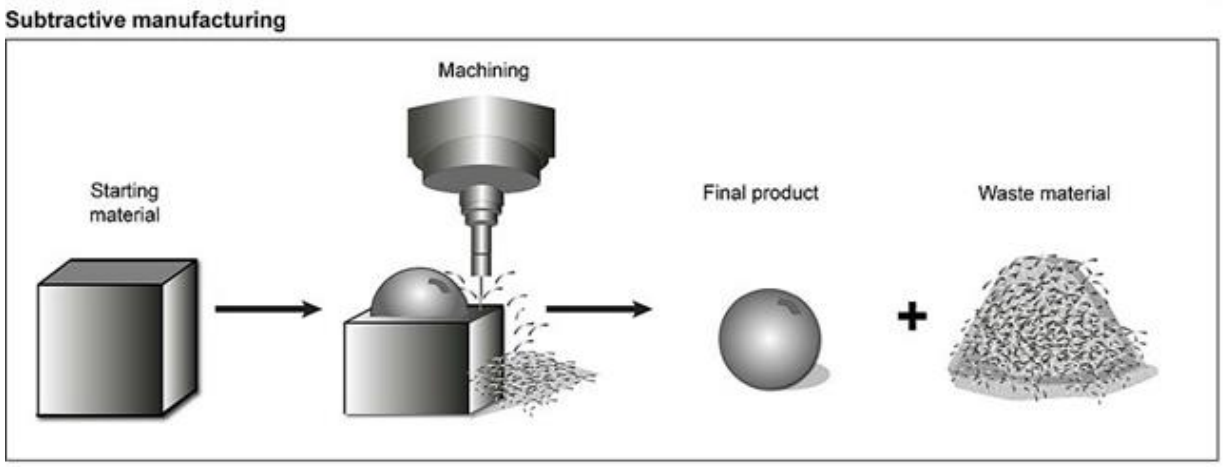
HiTEC

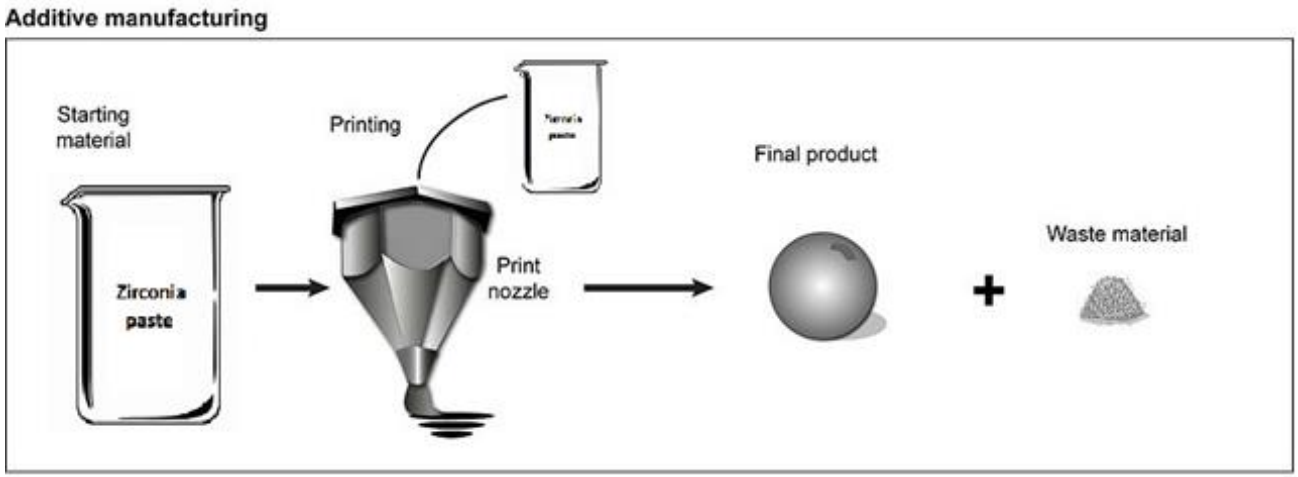
CTCV

Paste composition
350 g of ZrO_2
75.6 g of water
8.75 g of corn syrup
10.5 g of fructose
0.84 g of Zusoplast C92
0.105 g of Dolapix CE 64

Subtractive manufacturing (**SM samples**)

Additive manufacturing (Robocasting) (**AM samples**)





3. Characterization techniques

Density
(Archimedes
method)

Porosity
(Optical
microscopy)

Hardness
(Vickers)

Surface roughness
(Surface Roughness Tester)

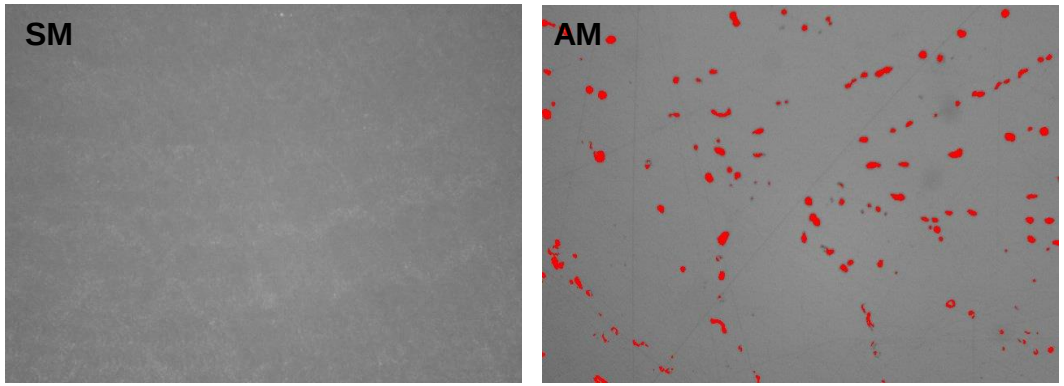
Wear
(chewing simulator)

Morphology
(SEM)

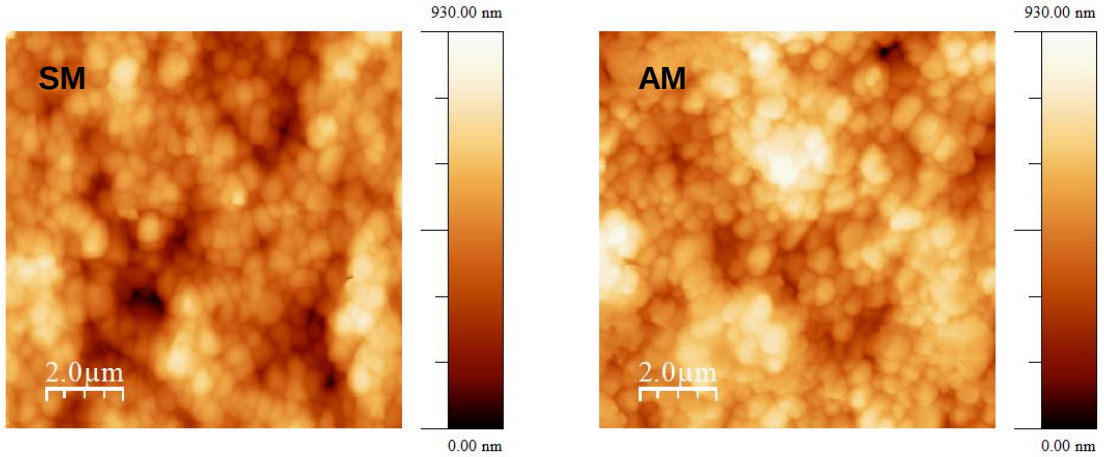
Cytotoxicity

4. Results - Zirconia samples characterization before wear testing

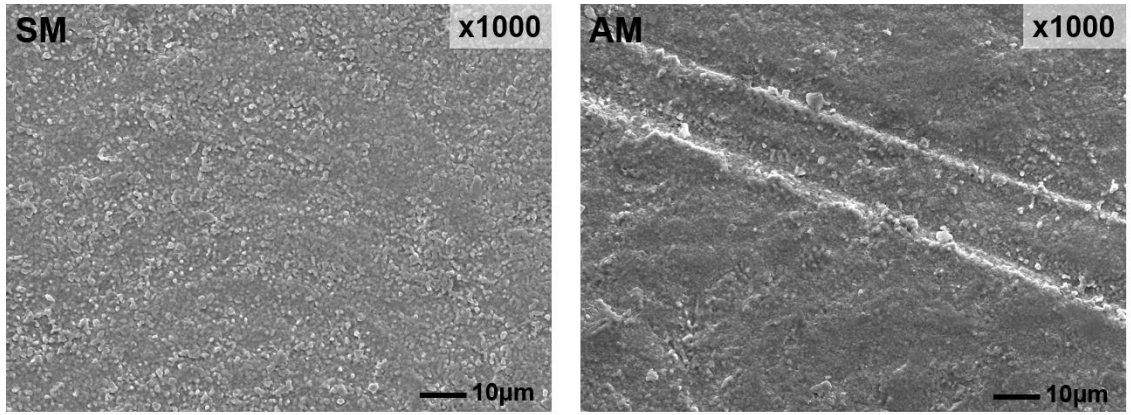
	SM samples	AM samples
Density (g/cm^3)	6.06 ± 0.02	6.04 ± 0.41
Porosity (%)	0.10 ± 0.02	2.95 ± 0.91
Vickers hardness (HV)	1400 ± 27	1130 ± 98
Toughness (MPa.m$^{1/2}$)	5.6 ± 0.7	4.5 ± 1.2
Roughness (nm)	267 ± 32	835 ± 35



Optical microscopy



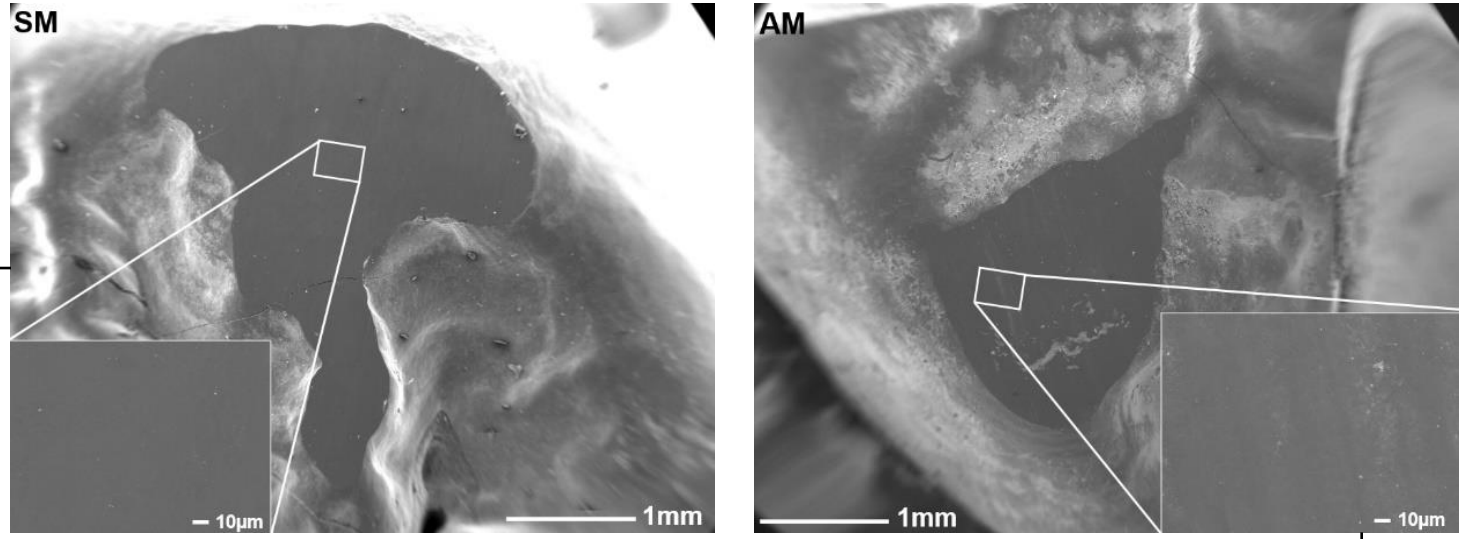
AFM



SEM

4. Results – Tribological studies

❑ Dental samples

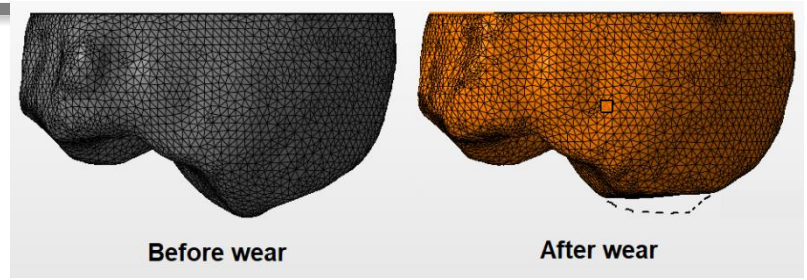


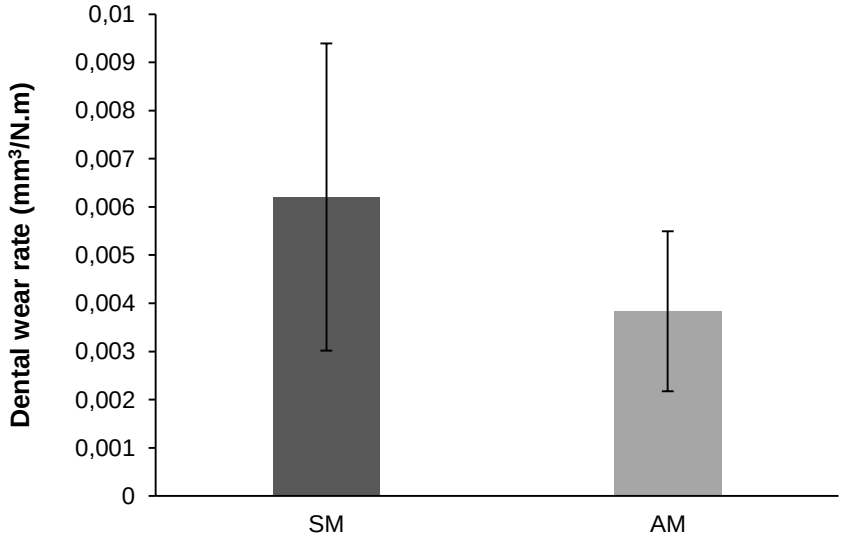
SEM images of the cusps' surface tested against SM and AM samples

Worn cusps' surface has a polished appearance without almost any signs of scratches

Cusps presented some scratches

Autodesk Netfabb software

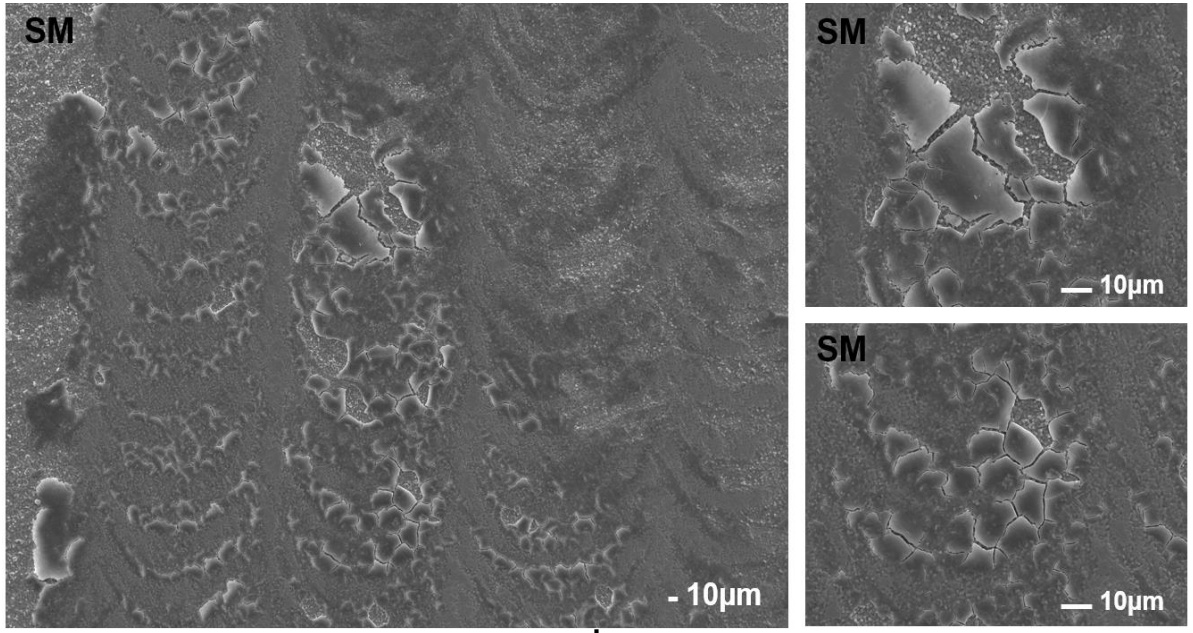


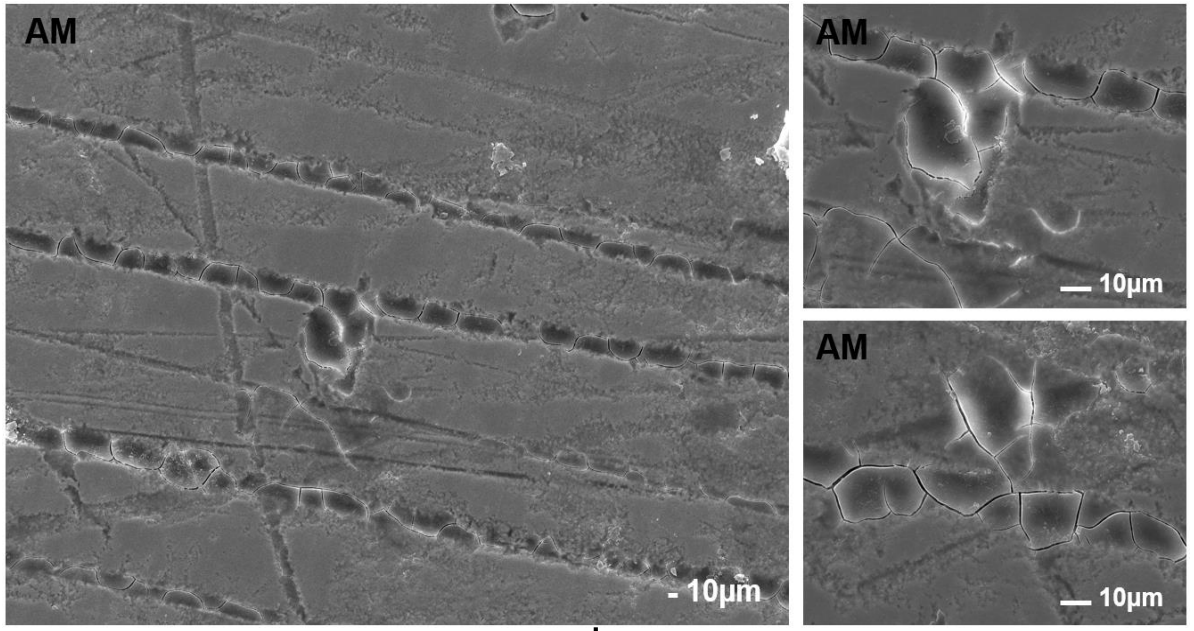


4. Results – Tribological studies

- **SM and AM zirconia samples**

SM and AM samples did not suffer visible wear during chewing simulation tests

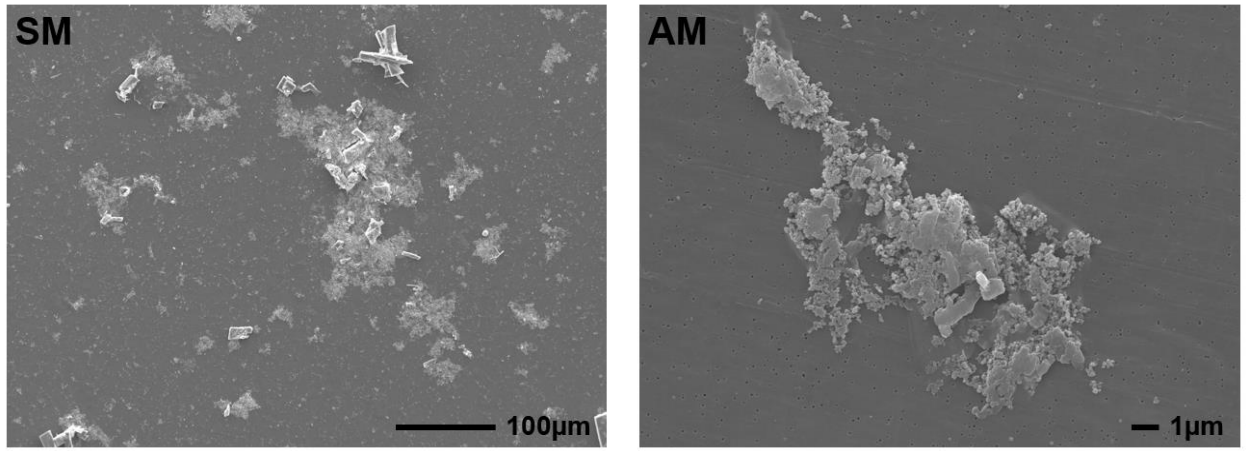




Thick layer of adhered dental material, which covers almost all the tested area during chewing simulation

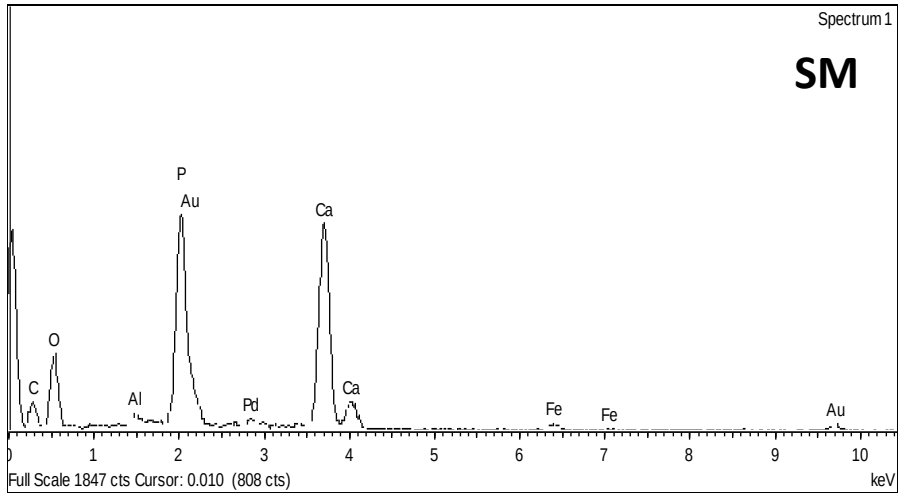
AM samples present some scratches over the surface in which the worn dental particles adhered

4. Results – Worn particles from the wear testing solution

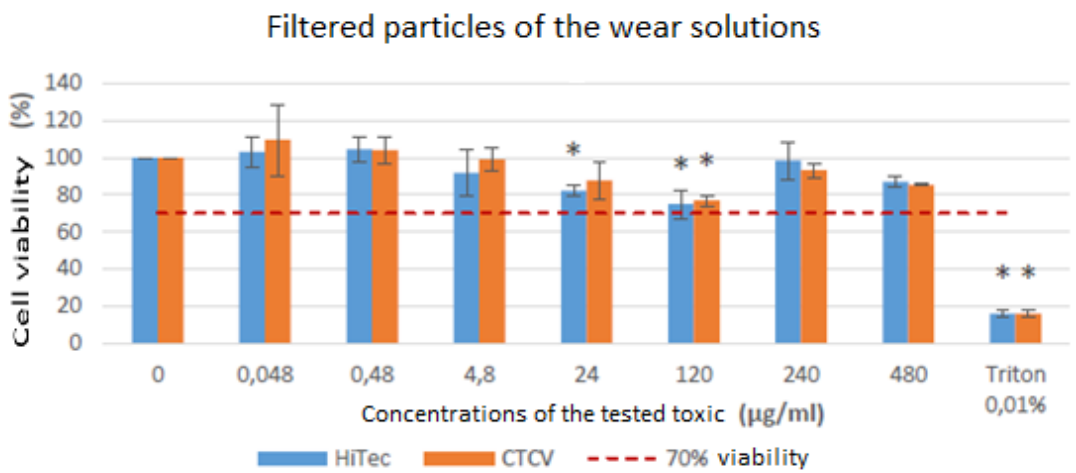


SM and AM filtered worn particles from the artificial saliva solution after wear testing

EDS analysis showed that both filtered solutions had essentially dental worn particles (calcium phosphate) after wear testing

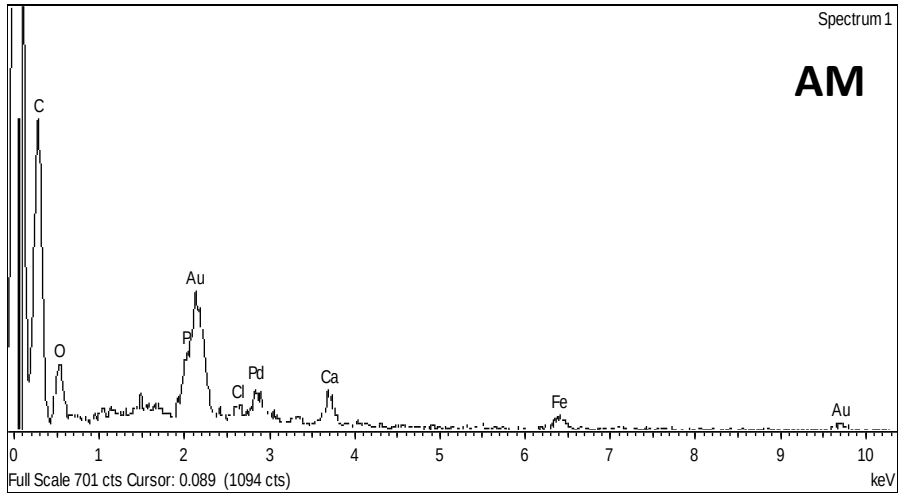


Cytotoxicity



Non toxic dental particles

The **shape** and **size** of the particles may condition toxicity



5. Conclusions

- Robocasting seems to be a promising technique to produce dental pieces.
- The performance of the produced piece results from a combination of factors that according to the results show that AM technique is a competitor with SM technique.

6. Future work

- Mechanical tests on the produced SM and AM pieces
- Apply a glaze over the samples surface (e.g. HiTEC uses it in all of their works)

Thank you!