Minho University
Guimarães
PORTUGAL

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Center for Mechanical and Materials Technologies

Functionalized Materials and Surfaces Performance Group

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Casting low-weight micro-structured materials – a new materials concept for jewelry components

Filipe Silva, Delfim Soares, Nuno Peixinho, Bruno Henriques, Paulo Pinto
Minho University – Guimarães - PORTUGAL

Motivation of the present work

- **High Price of gold**

- **Lower purchasing power (in western countries)**

Pushing for low weight high resistant materials !!!

Does it already exists?

- **Yes !!**

Hollow casting is an old technique !!!

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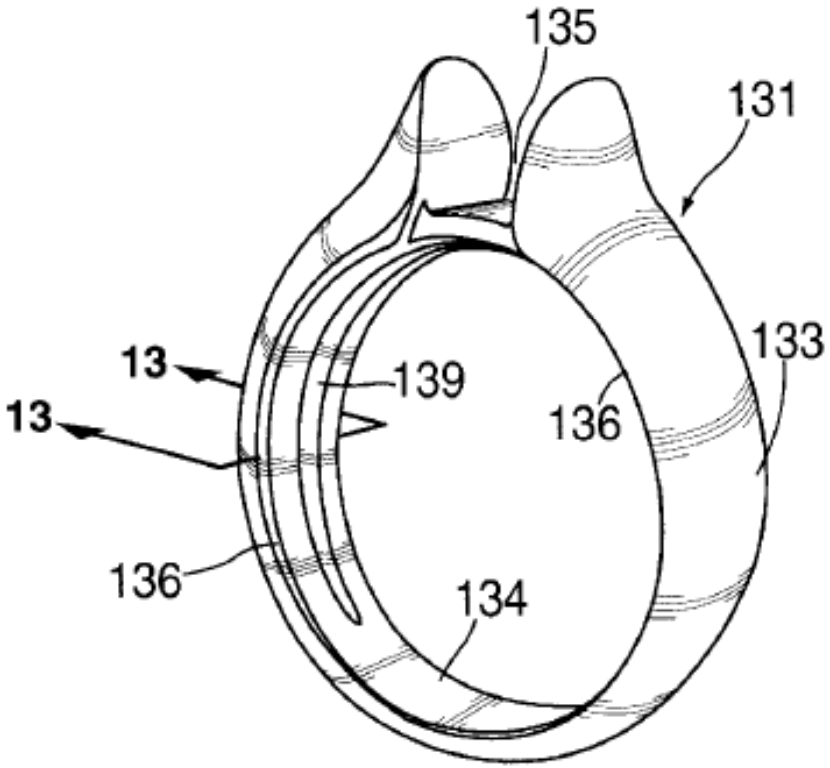
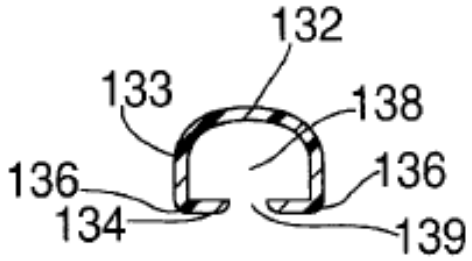
Does it already exists?





Eddie Bell

Does it already exists?

- **Yes !!**

By welding different parts !!!

Cast parts;
Stamped parts;

Or by using other processing technologies:

Electro-forming;
Laser sintering;

Drawbacks of existing solutions?

- **Welding parts:**
  - Laborious and slow process (requires assembling, adjusting, welding, polishing,…);
  - Possible only for simple geometries
  - Difficult to weld thin walls.

Drawbacks of existing solutions?

- **Electro-forming:**

➢ **very slow process;**
➢ **Pieces get damaged/distorted due to thin walls.**

Drawbacks of existing solutions?

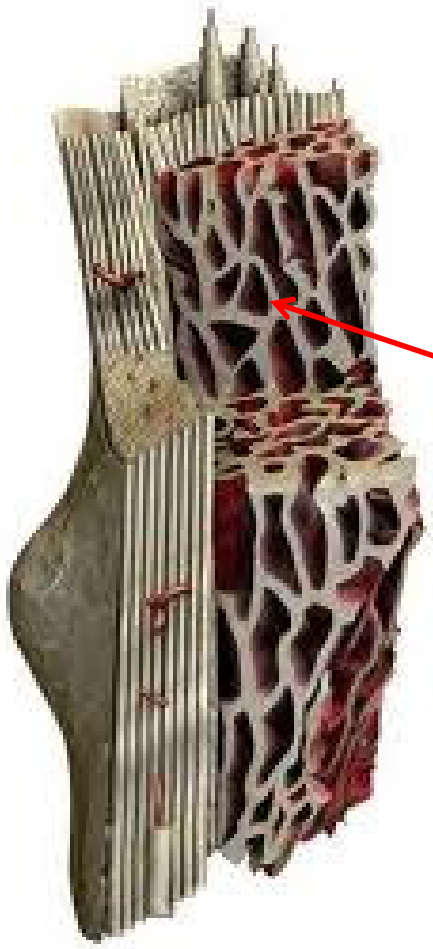
- **Laser sintering:**
  - **very slow process;**
  - **Polishing is difficult.**

Fig. 6. Ring with self-standing structure.

Beatriz Biagi

Wall thickness of about 0,2-0,4 mm and complex shapes with elimination of traditional production steps (model making, rubber moulding; wax injection, casting)

The micro-structured materials concept.

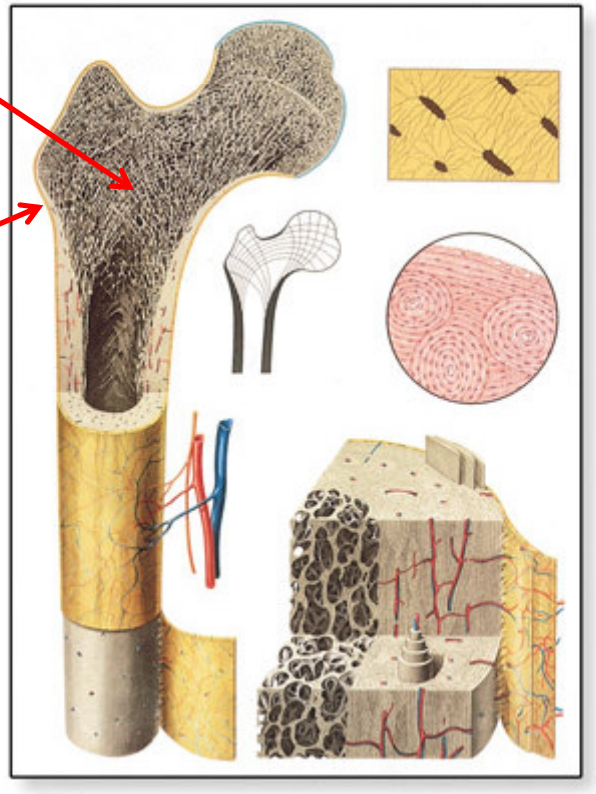


Learning from nature

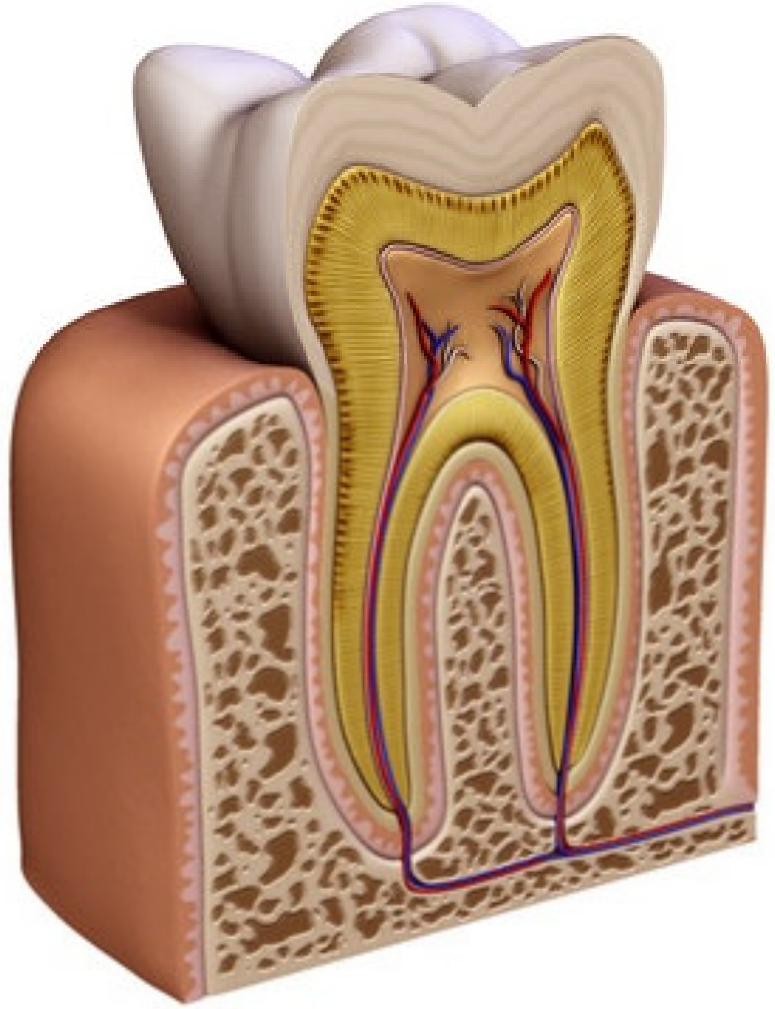
Remove the material from where it is not needed.

Internal cellular structure

Thin wall



The micro-structured materials concept.



Learning from nature

Remove the material from where it is not needed.

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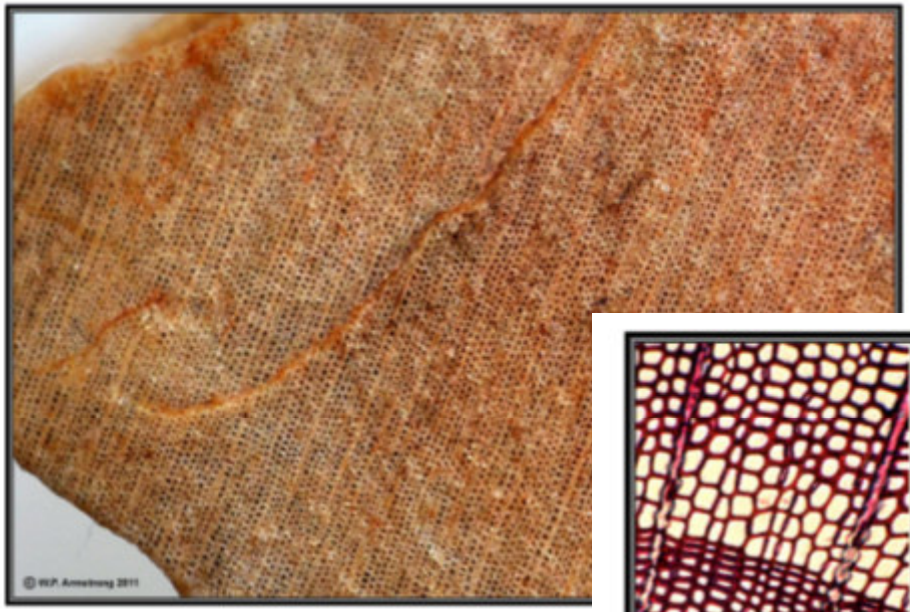
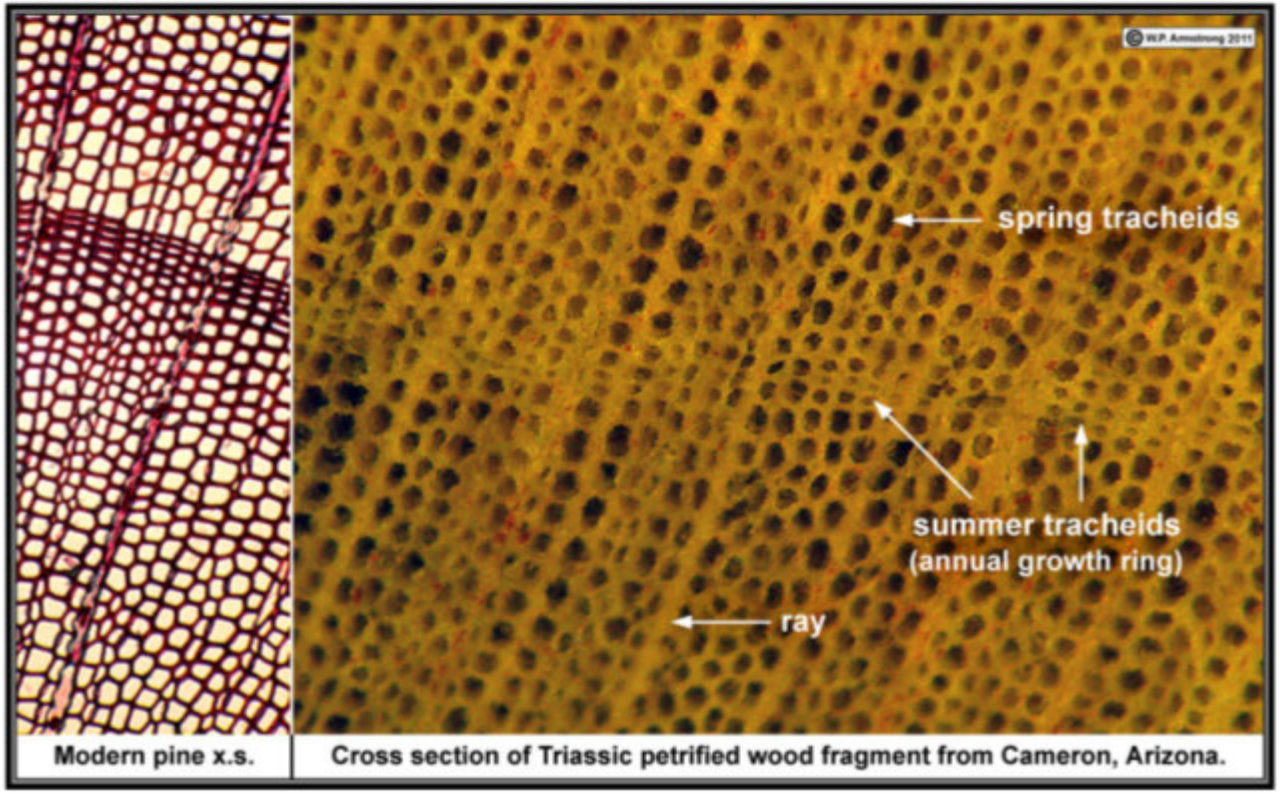
The micro-structured materials concept.



Learning from nature

Remove the material from where it is not needed.



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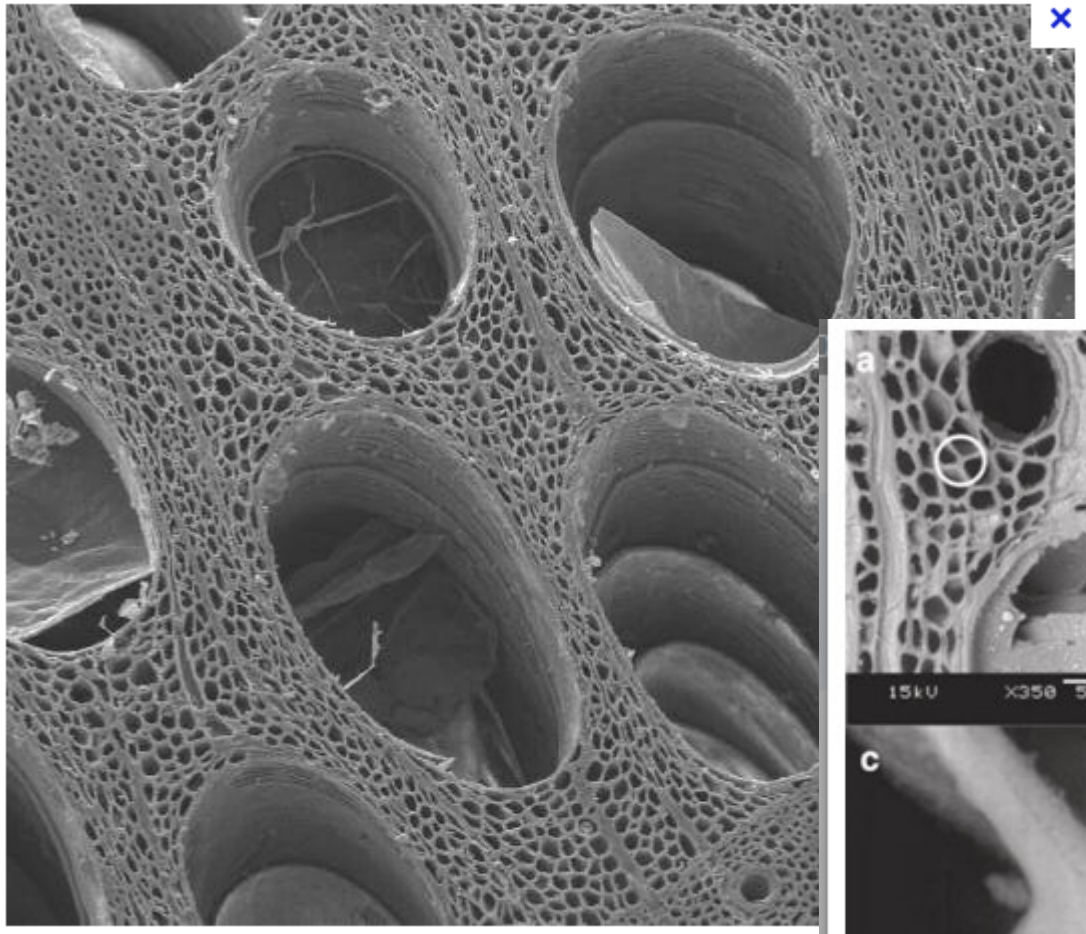
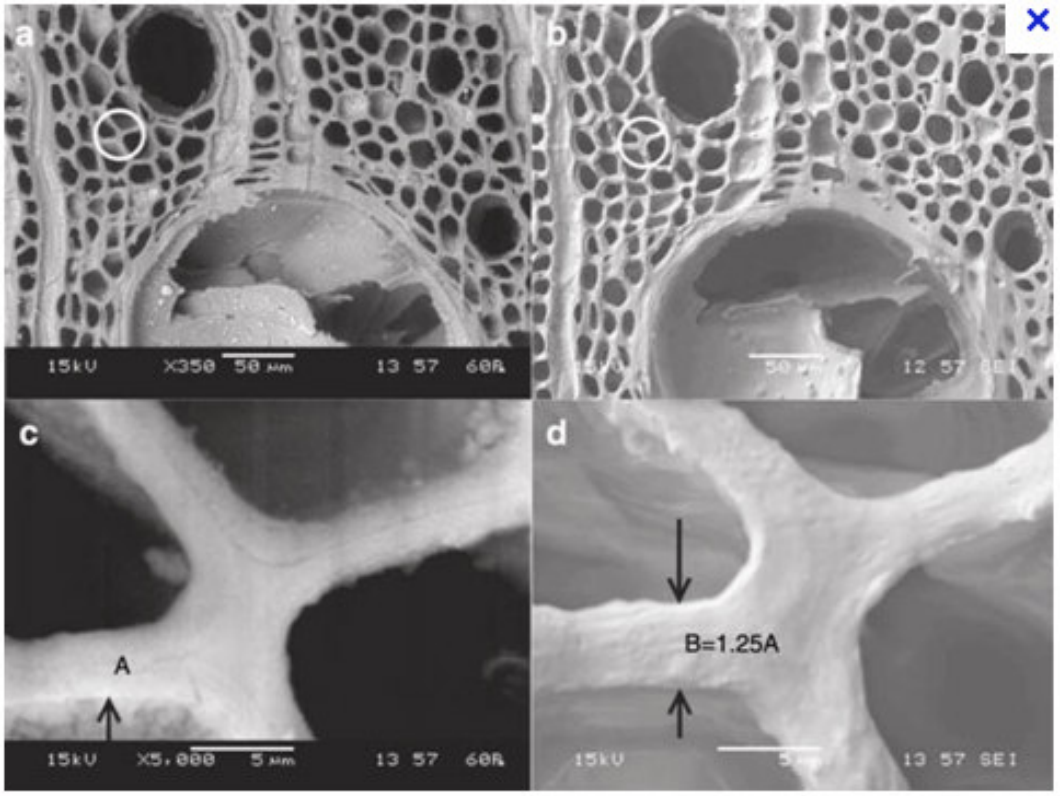
The micro-structured materials concept.



Learning from nature

Remove the material from where it is not needed.



The micro-structured materials concept.

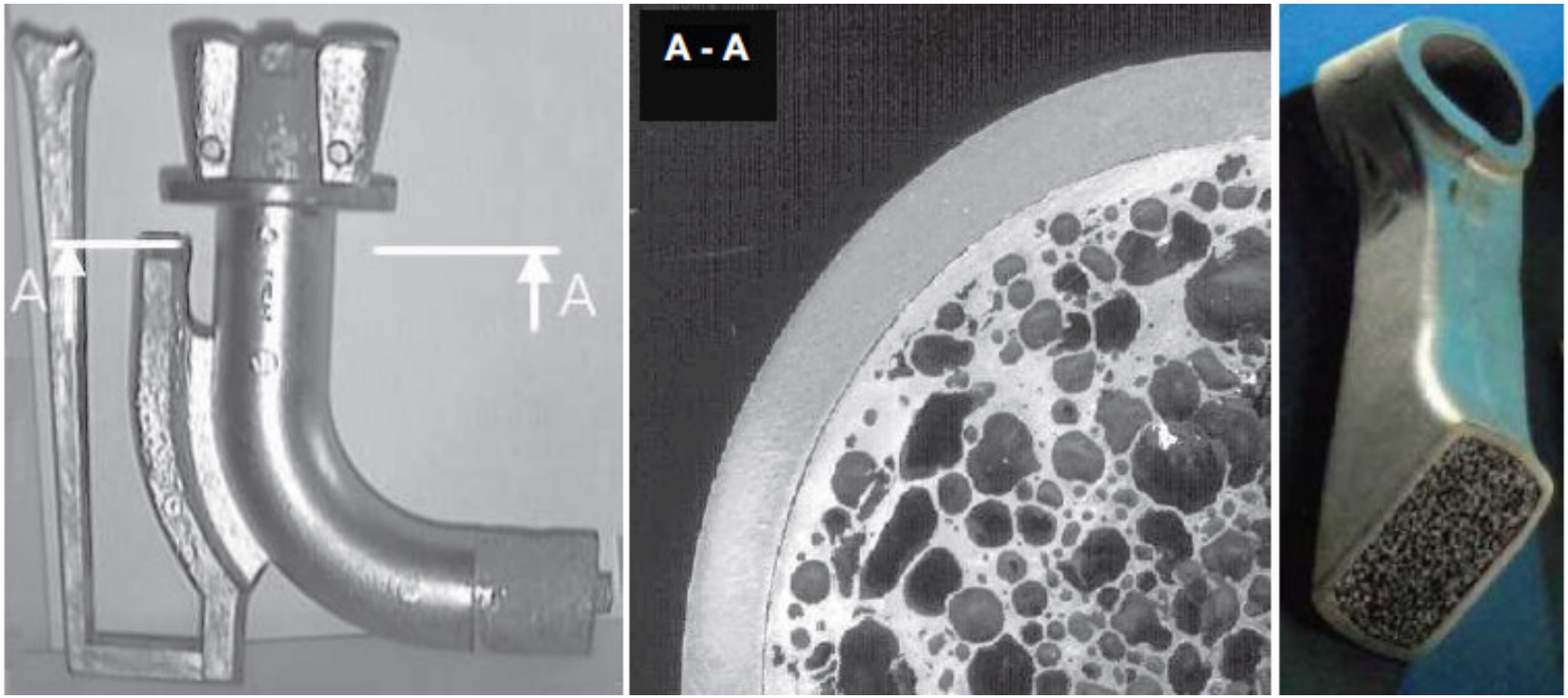
It is possible to produce high resistant and low weight materials !! By learning from nature !!

The micro-structured materials concept
What exists !

In other fields (automotive, aeronautic, biomedical, it has been tried to produce, by casting, metal foams.

The micro-structured materials concept
What exists !

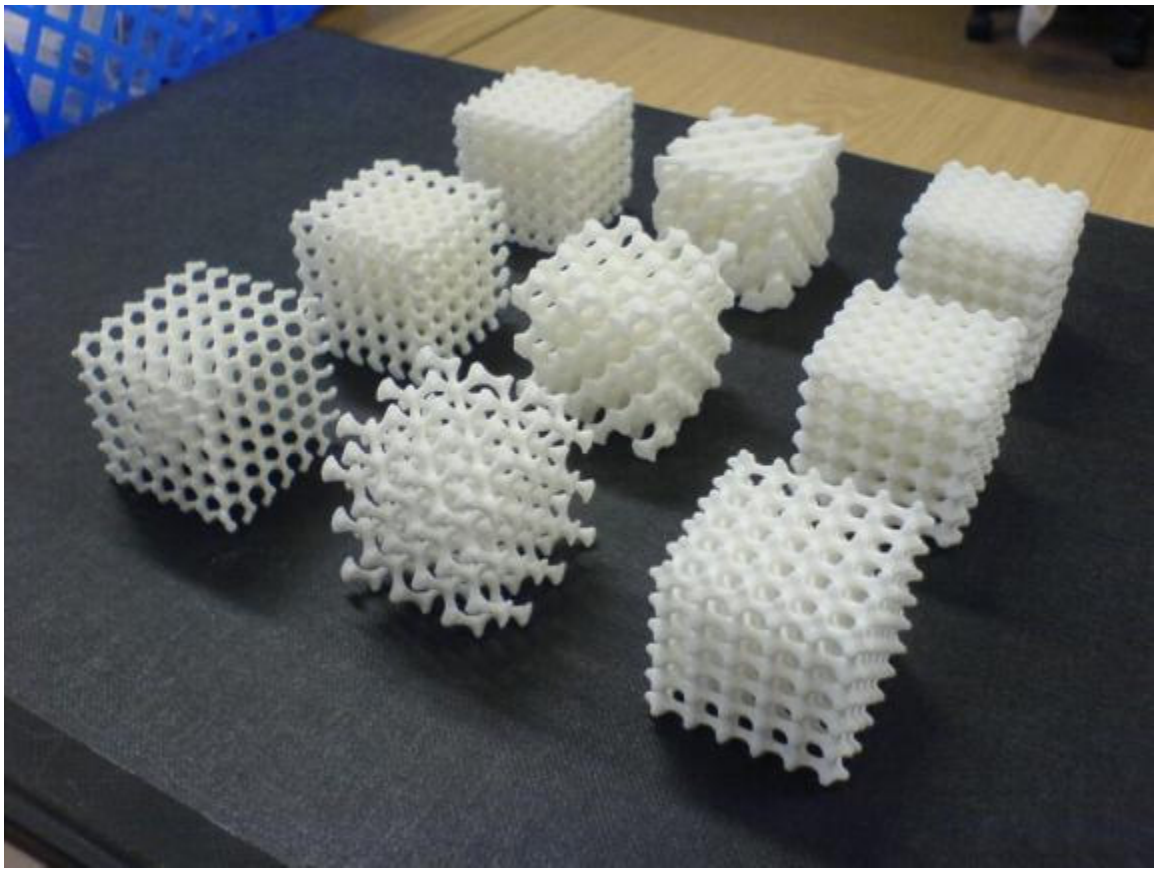
Further, it has been also tried to produce components with an inner metal foam, and an external skin.



Tricky and difficult process with lots of problems !!!

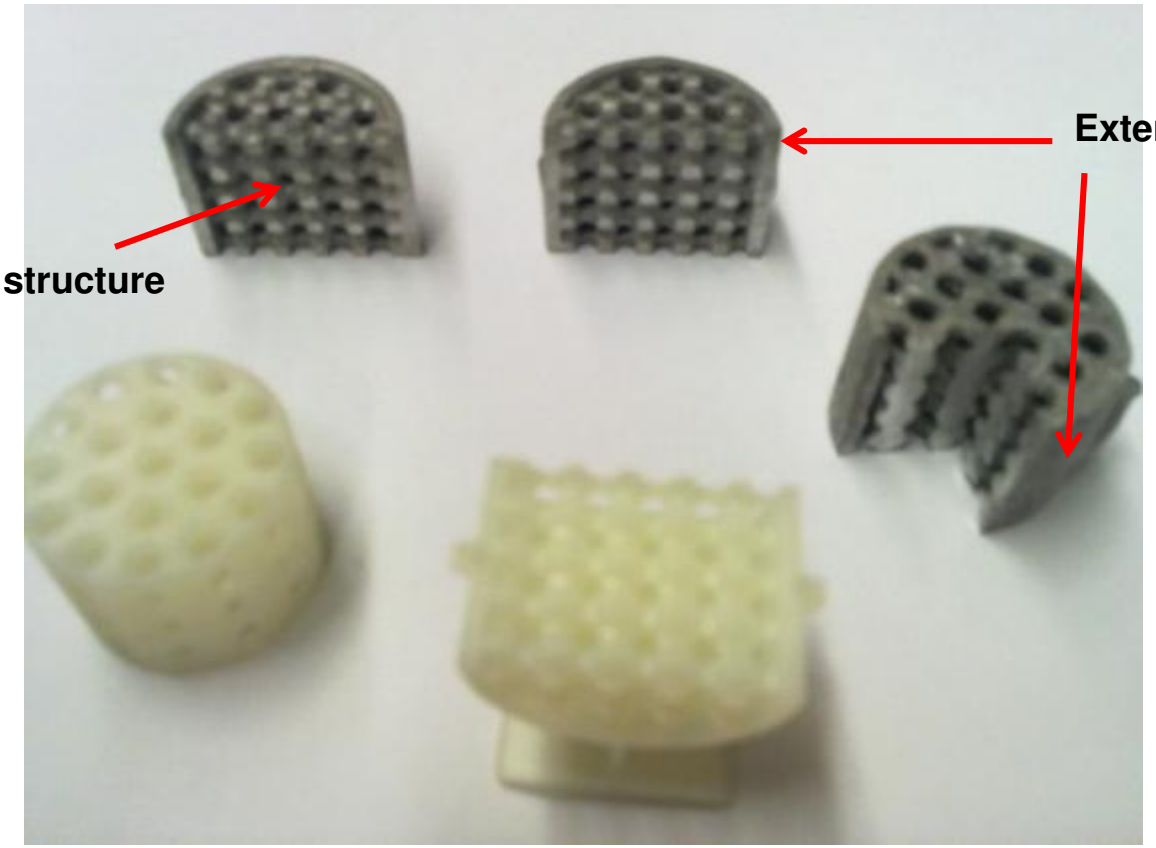
The micro-structured materials concept
What exists !

With the advent of stereolitography it is possible to build internal microstructures.



The micro-structured materials concept
What exists !

With the advent of stereolitography it is possible to build internal microstructures with any kind of external walls.



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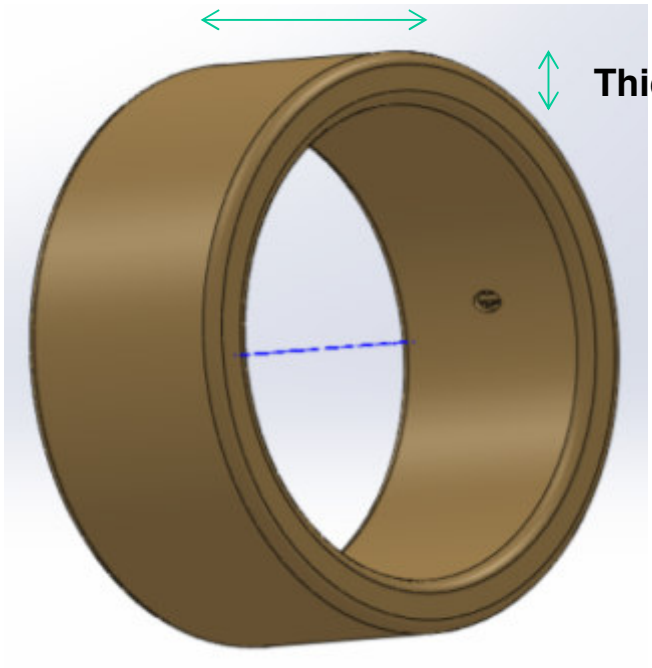
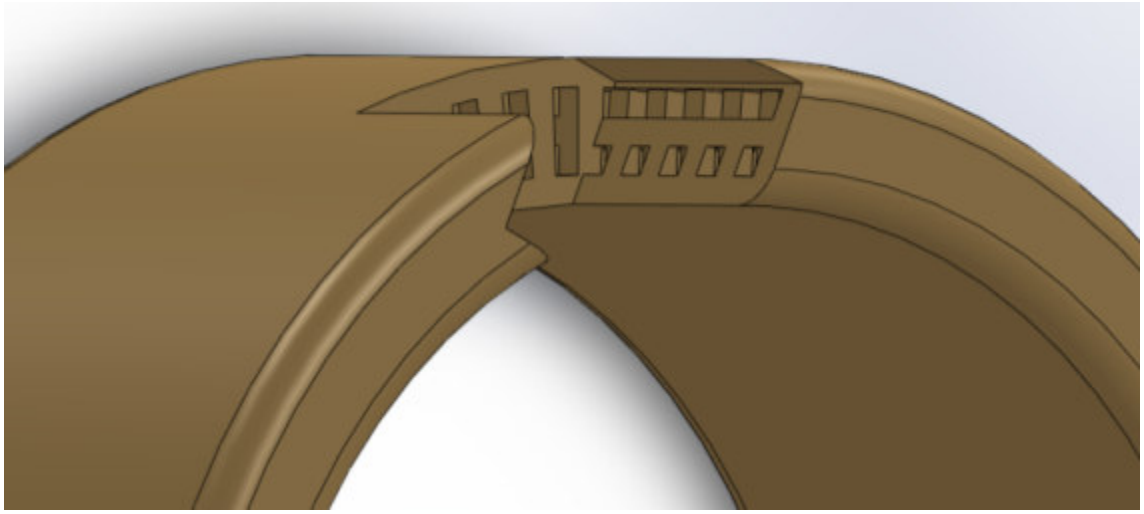
The micro-structured materials concept.

What can be done !



It is possible to define the external skin and the internal wall according to shape (external wall) and resistance (internal structure).



Pending patent: PT106228

Micro-structured materials – low weight and high resistance

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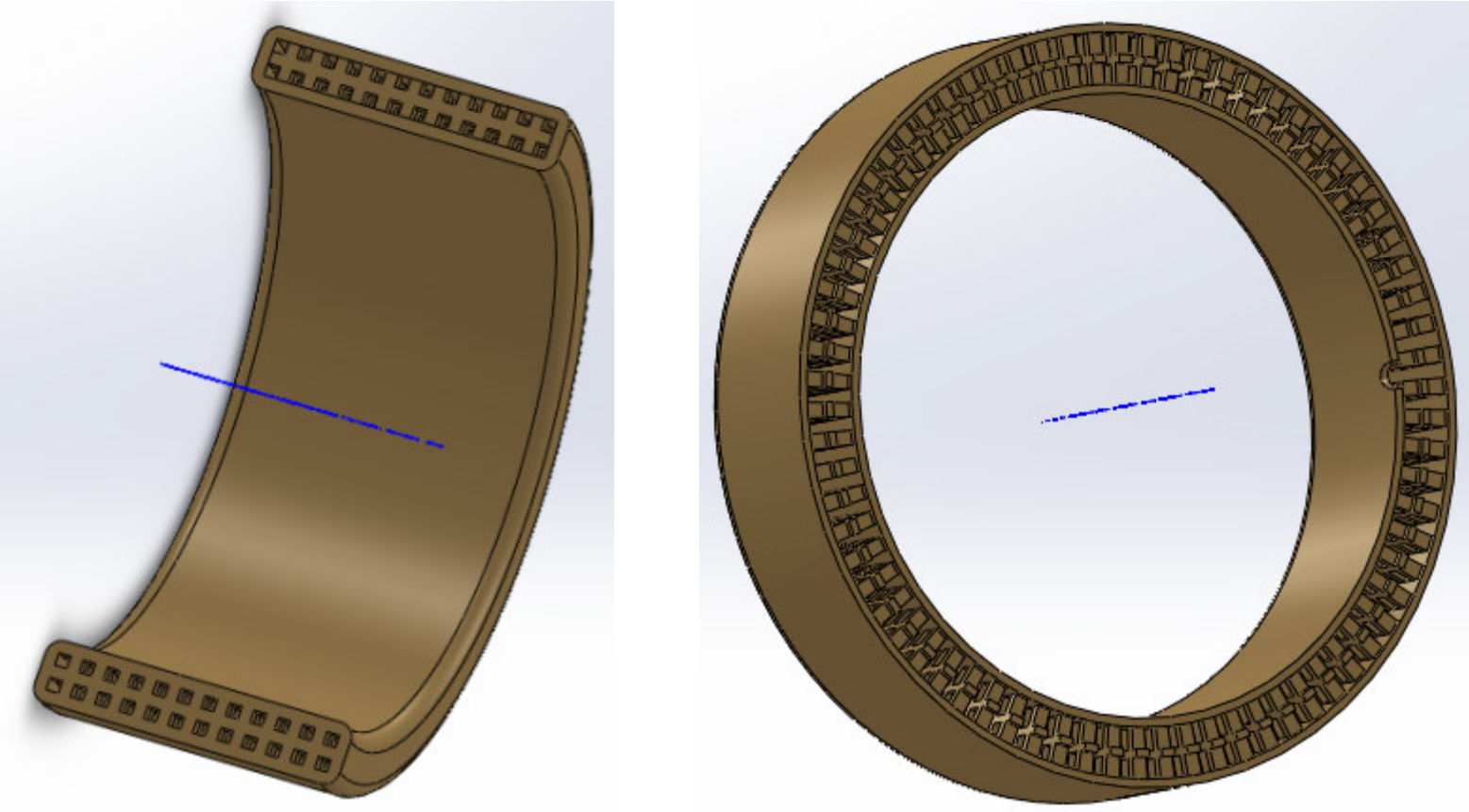
The micro-structured materials concept.

What can be done !



Micro-structured materials – low weight and high resistance

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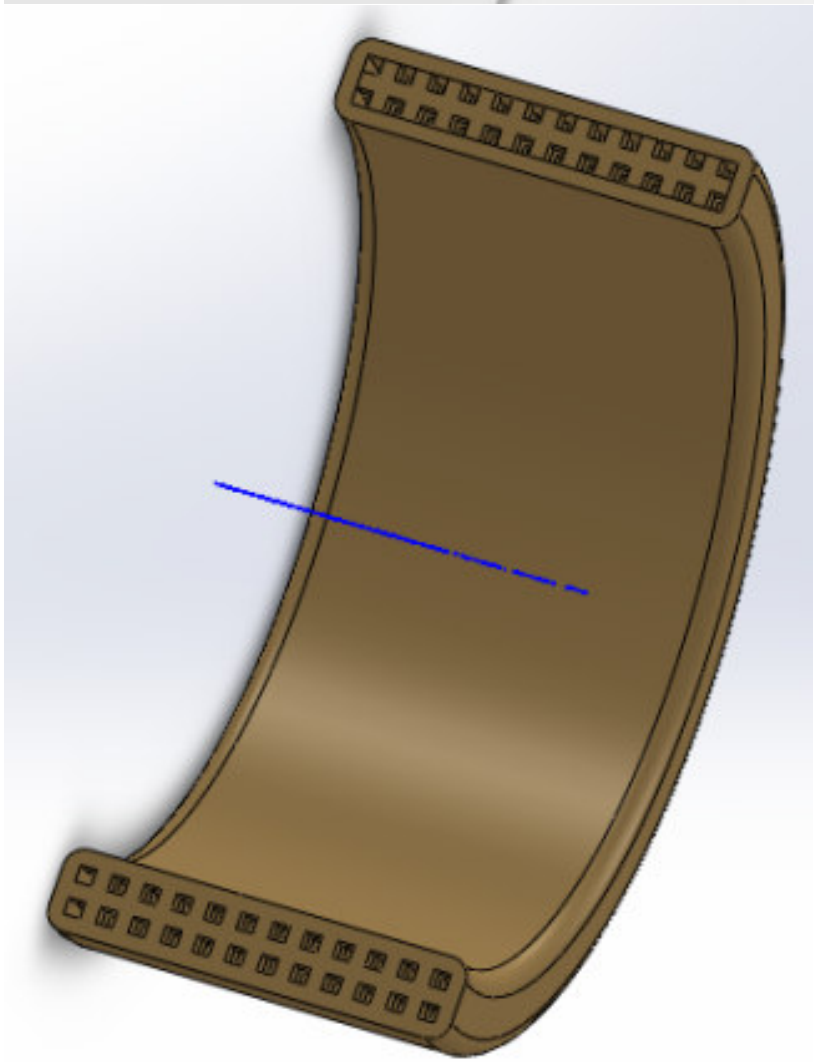
The micro-structured materials concept.

What can be done !



Wall thickness of 0,4 mm →
38% saving in weight;

Wall thickness of 0,25 mm →
55% saving in weight;

(as compared to a dense ring)

Micro-structured materials – low weight and high resistance

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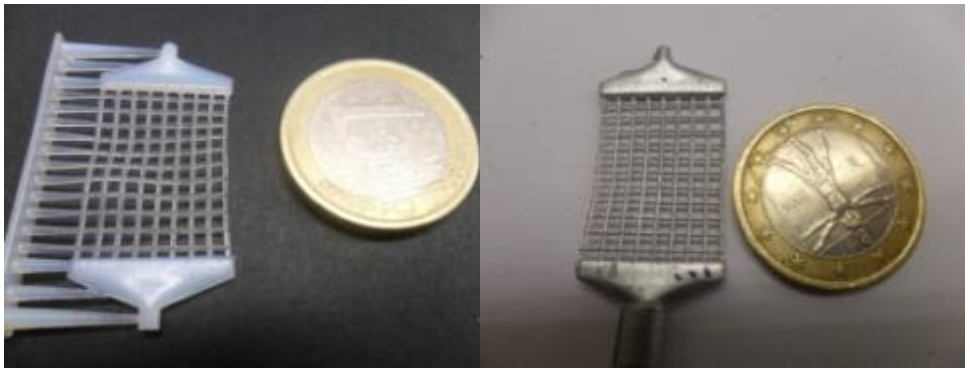
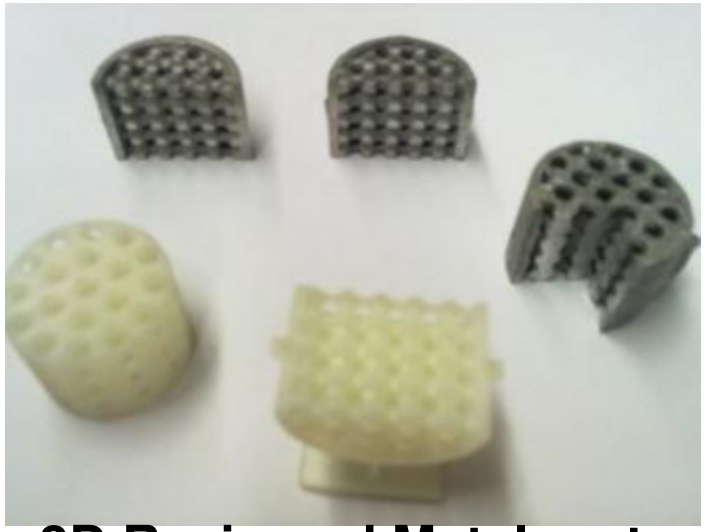
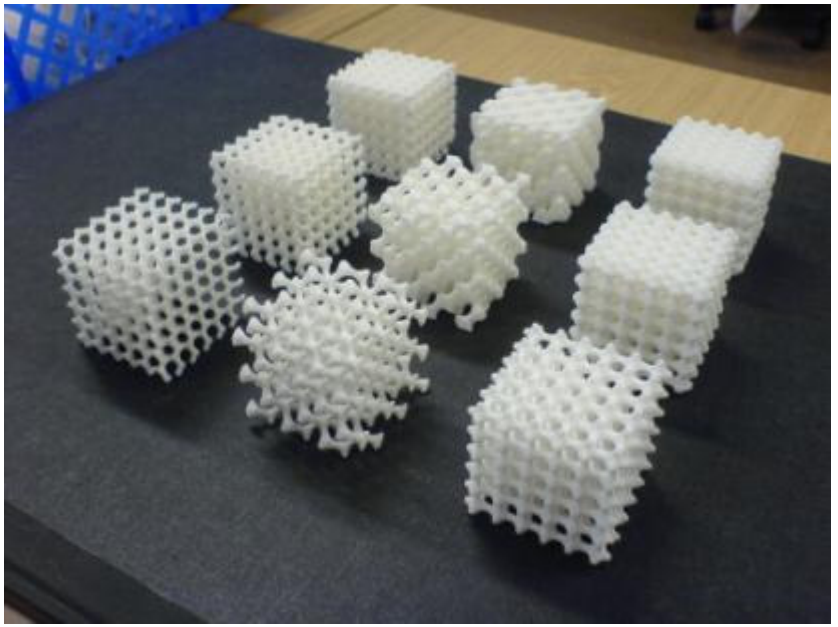
The micro-structured materials concept. Ongoing research (results)



2 D Resin and Metal parts



3D Resin and Metal parts



- Melt Temp.
- Mould Temp.
- Pressure
- Vacuum
- Vibration for filling
- disinvestment

Micro-structured materials – low weight and high resistance

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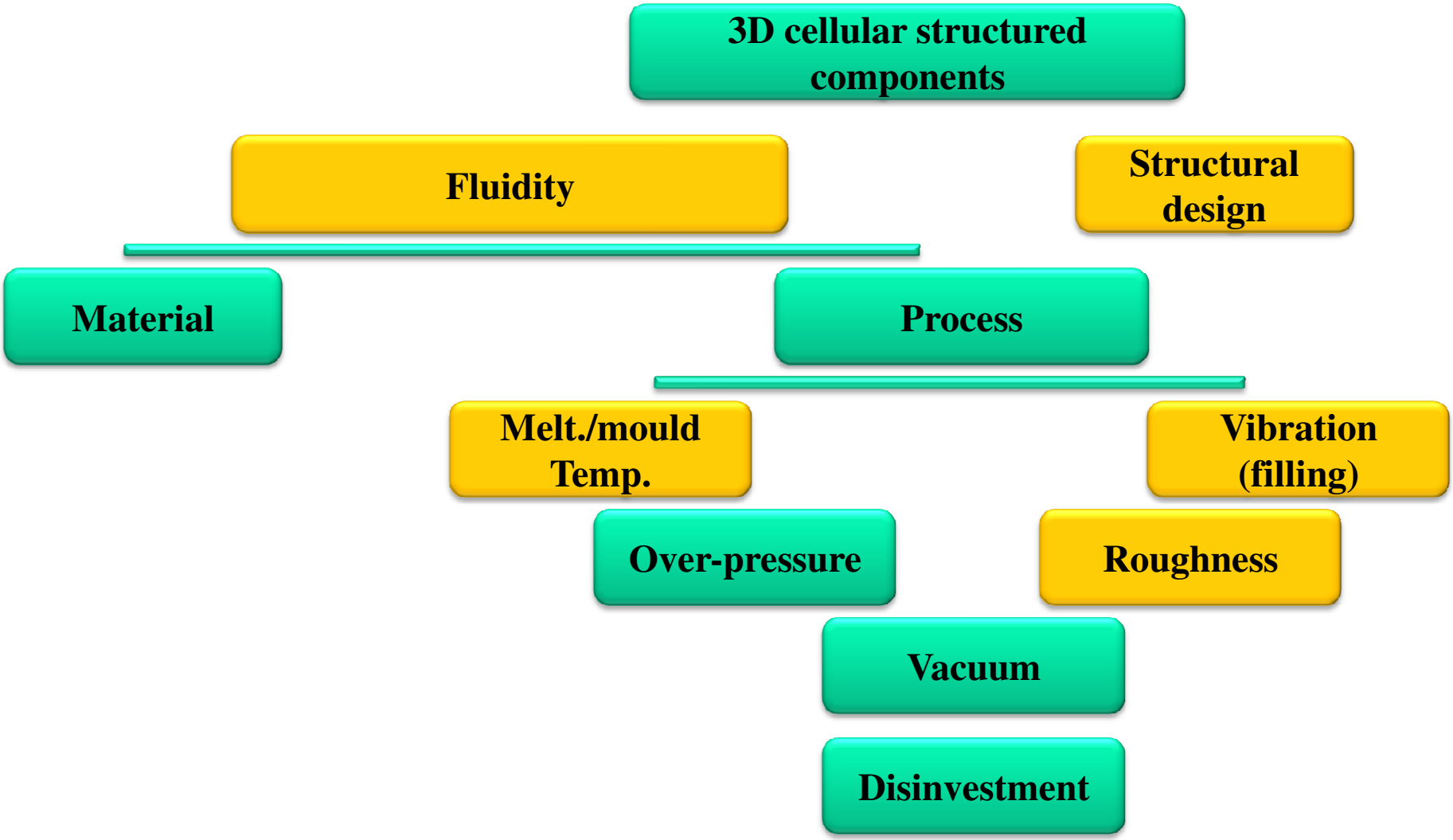
The micro-structured materials concept. Ongoing research (important variables)

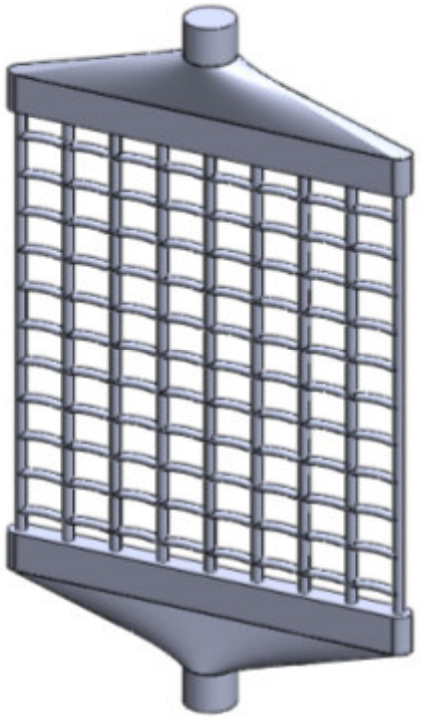


The micro-structured materials concept.

Experimental details

Melt./mould Temp.

- Alloy
  - A413 (Al-12Si-1Cu-1Fe)
- Geometry:
  - Square shape Cells



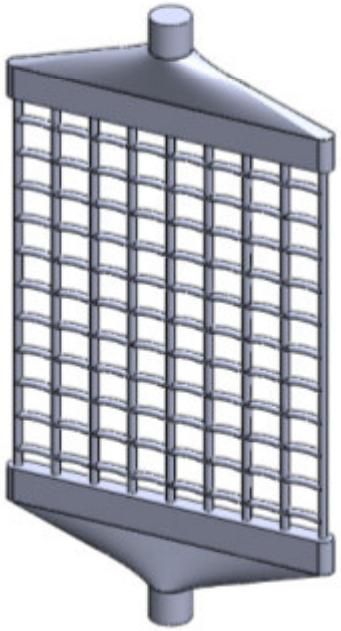
Geometry of the choosen specimen

The micro-structured materials concept.

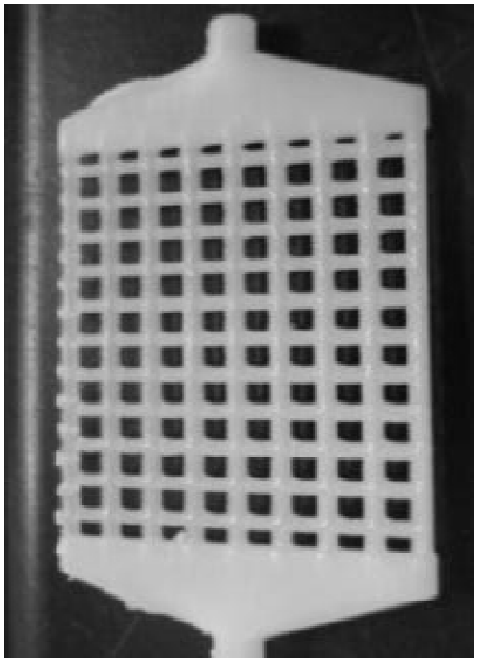
Experimental details

Melt./mould Temp.

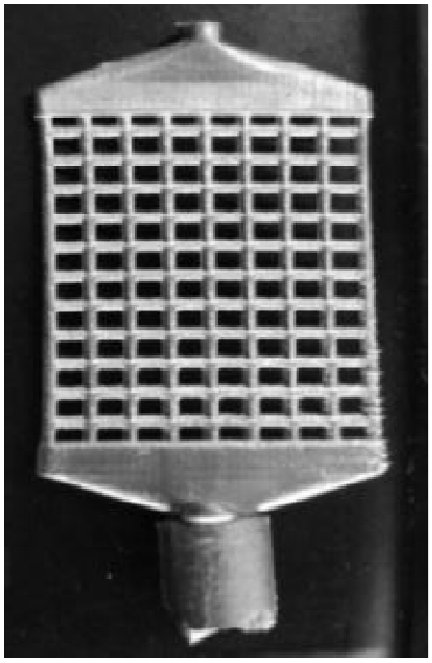
- Casting Process



3D drawing



rapid prototyping model

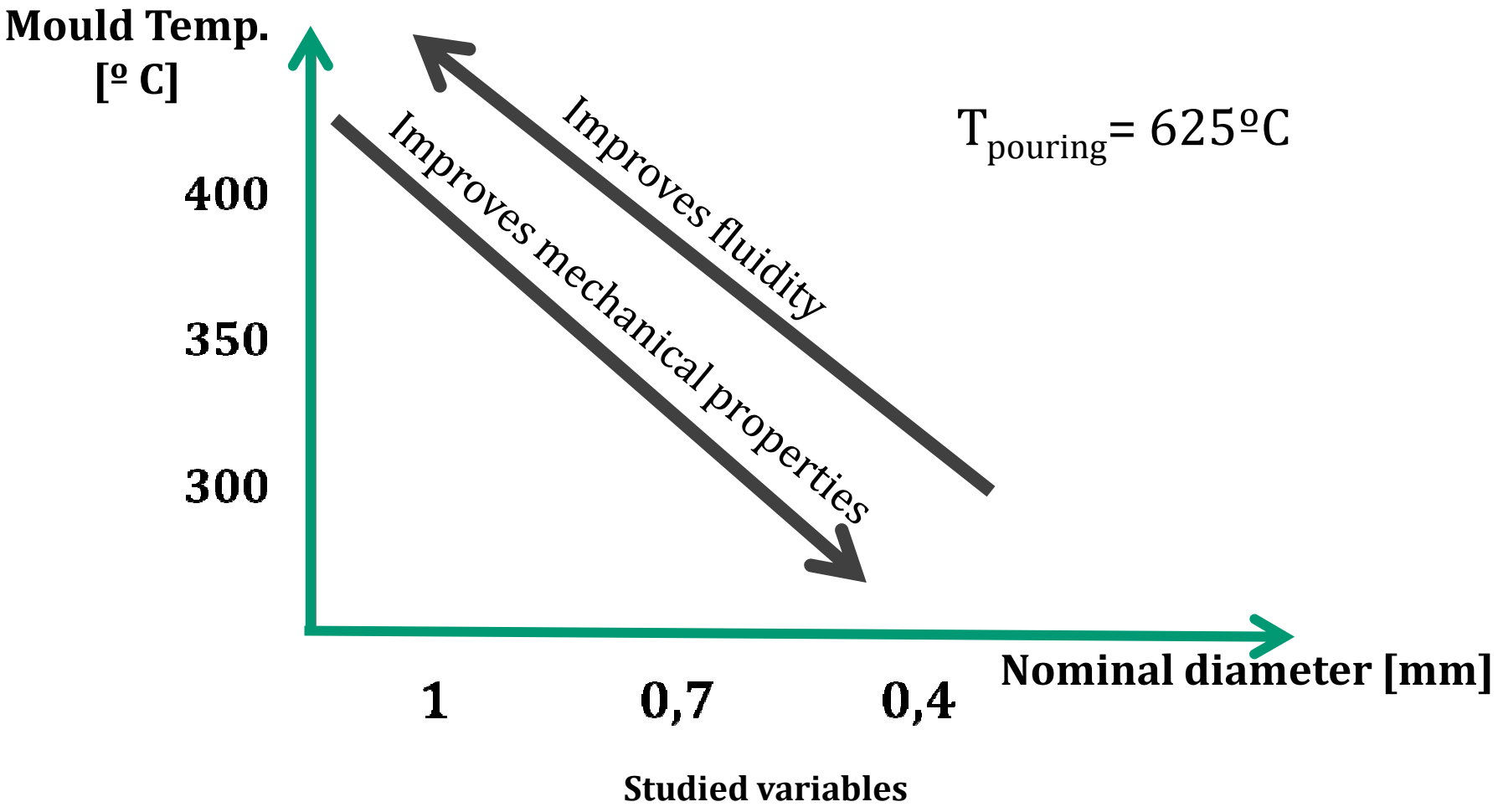


obtained casting specimen

The micro-structured materials concept.

Experimental details

Melt./mould Temp.

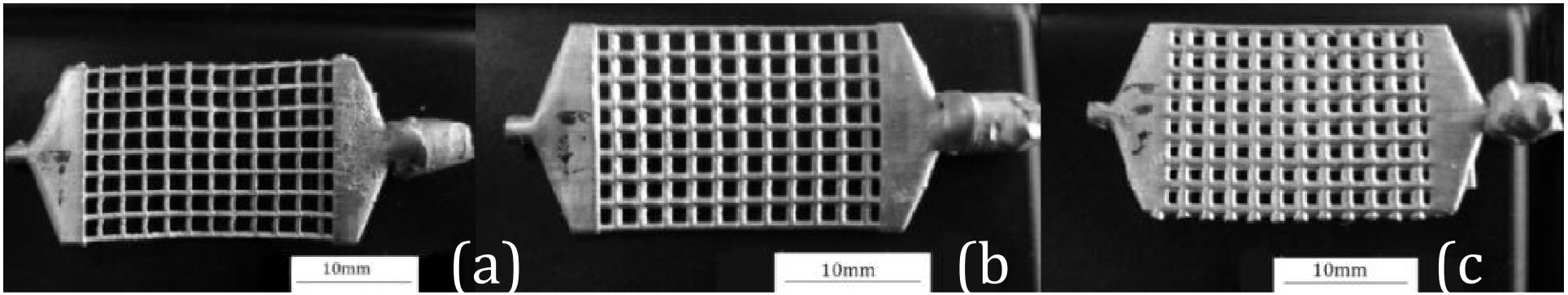


The micro-structured materials concept.

Experimental details

Melt./mould Temp.

- Quality of casting (geometry)
- Microstructure
- Mechanical Properties



Samples obtained for an experience : pouring temp.: 625ºC ; mould Temp.: 350ºC.;
(a) 0,4mm; (b) 0,7mm (c) 1mm.

The micro-structured materials concept.

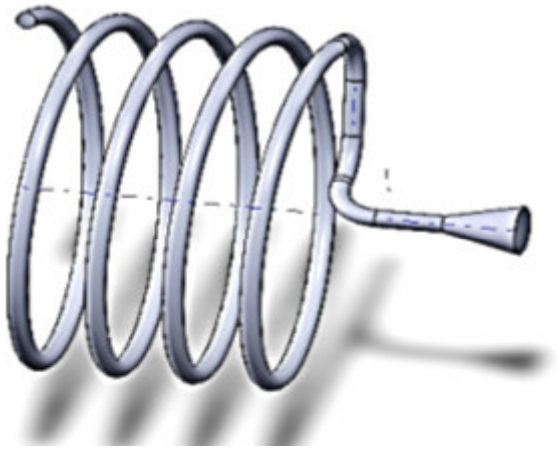
Experimental details

Melt./mould Temp.

- Fluidity evaluation

Fluidity evaluation for different mould temperatures

Length of spiral wire [mm]		
300ºC	**350ºC**	**400ºC**
23,56	31,41	62,83



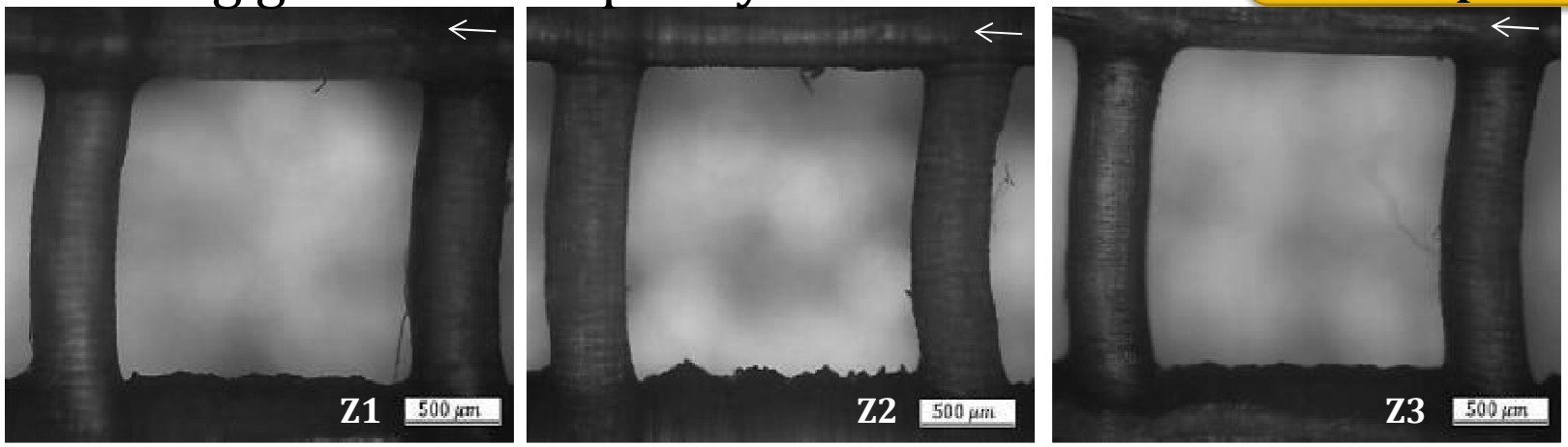
Drawing of spiral used for fluidity evaluation. Nominal diamater of wire: 0,4mm.

The micro-structured materials concept.

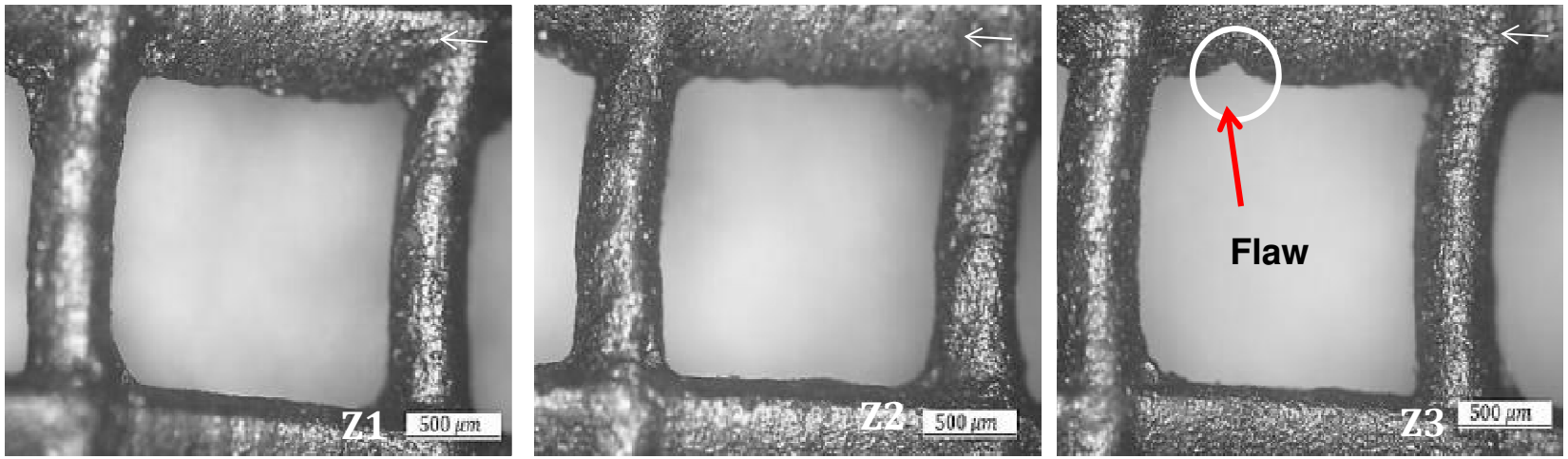
Experimental details

Melt./mould Temp.

- Processing geometrical quality



Cells of a resin prototypi with 0,4mm nominal diameter wire: Mould Temp.: 350ºC; Pouring Temp.: 625ºC. (Z1) Zone 1, (Z2) Zone 2, (Z3) Zone 3.



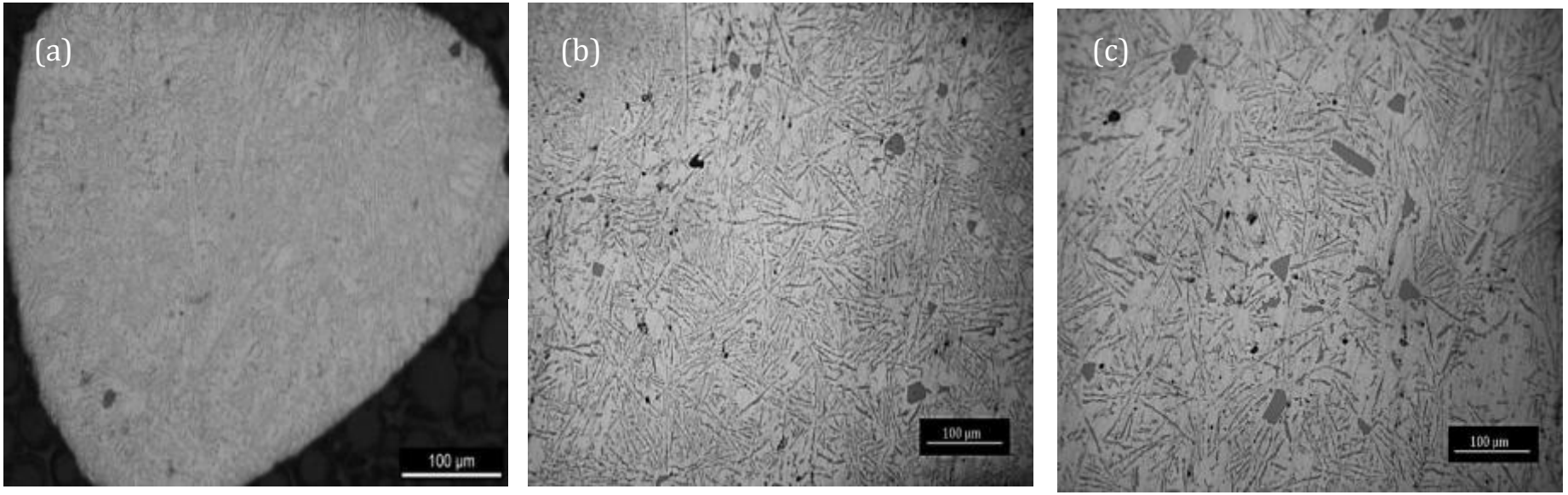
Cells of a cast with 0,4mm nominal diameter wire: Mould Temp.: 350ºC; Pouring Temp.: 625ºC. (Z1) Zone 1, (Z2) Zone 2, (Z3) Zone 3.

The micro-structured materials concept.

Experimental details

Melt./mould Temp.

- Influence of wire diameter on microstructure



Microstructure of samples poured at: 625ºC; mould temp.: 350ºC, for different wire diameters: (a) 0,4mm; (b) 0,7mm e (c) 1mm.

Lenght of eutectic silicon for samples with different wire diameter.

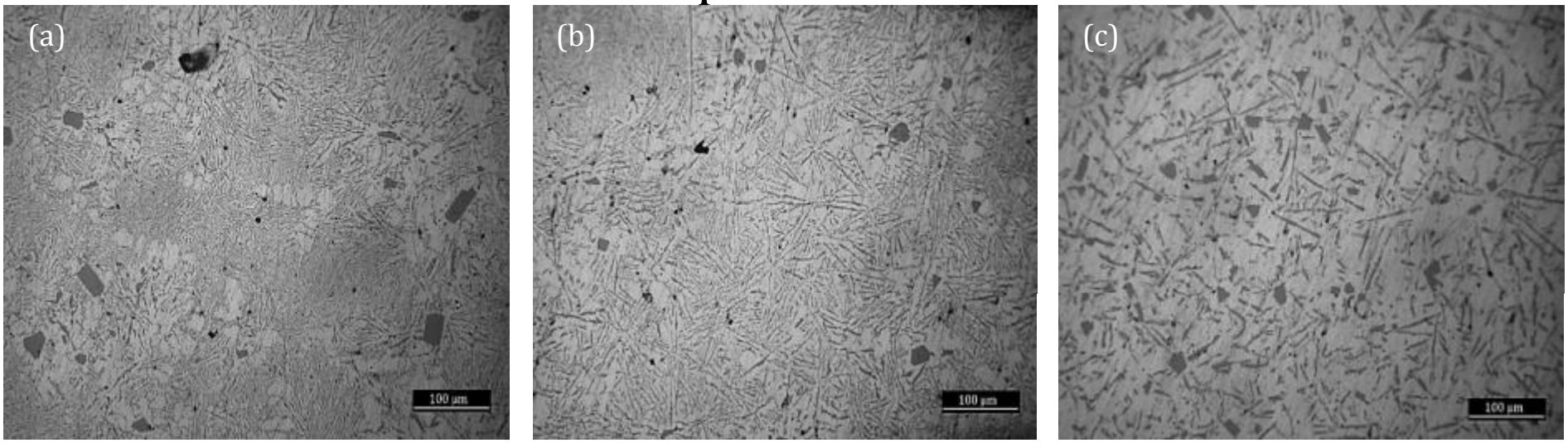
Nominal wire diameter [mm]	0,4	0,7	1
Average Length of Eutetic Silicon [µm]	9,21 ± 3,61	18,23 ± 6,95	19,39 ± 7,36

The micro-structured materials concept.

Experimental details

Melt./mould Temp.

- Influence of mould temperature on microstructure



Microstructure of samples with 0,7 mm wire nominal diamater, poured at 625ºC, in moulds with different temperatures: (a)300ºC; (b) 350ºC e (c) 400ºC.

Average lenght of eutectic silicon for samples with 0,7 mm wire nominal diameter, poured at 625ºC, in moulds with different temperatures: (a)300ºC; (b) 350ºC e (c) 400ºC.

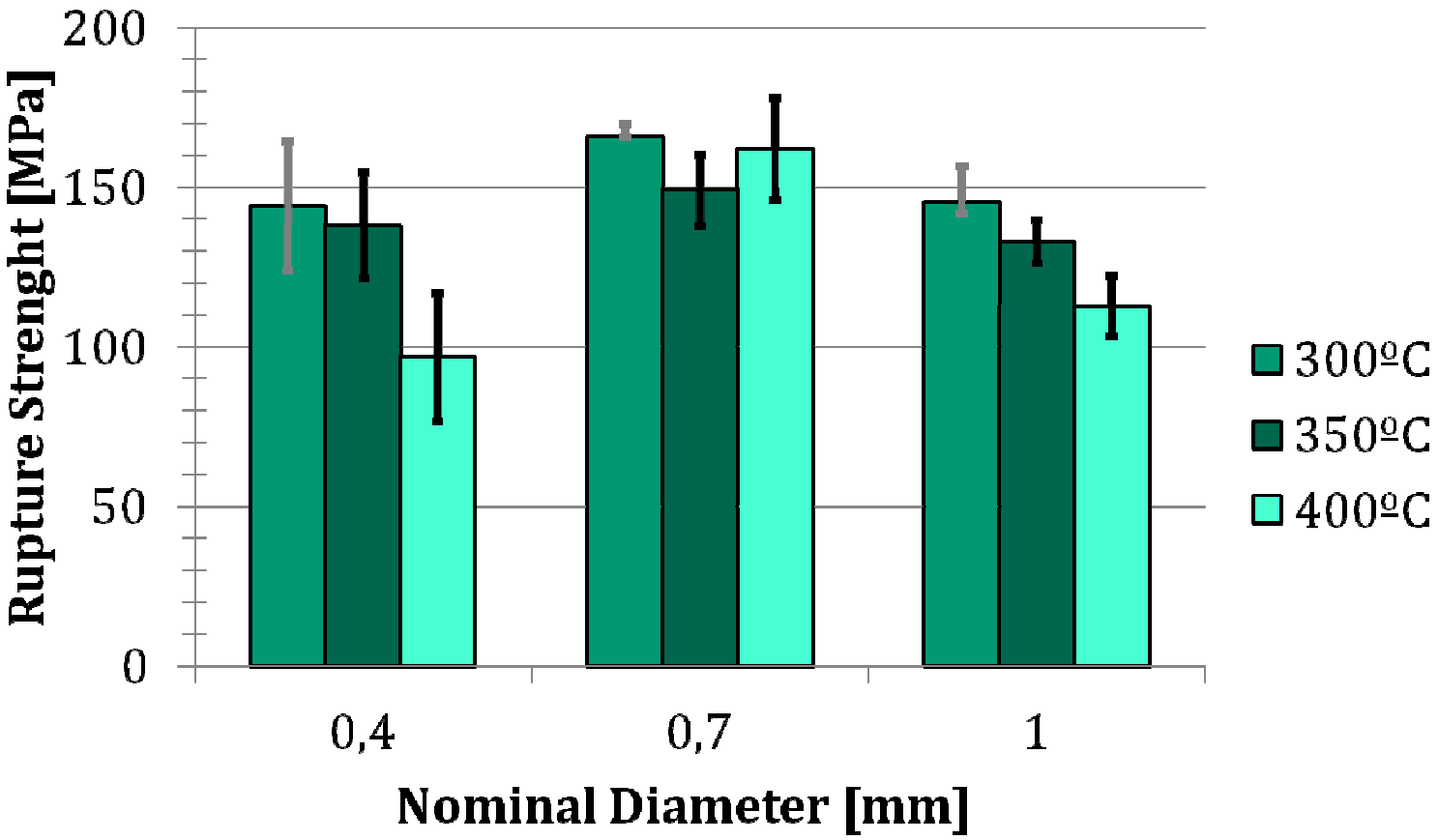
Mould Temperature [ºC]	300	350	400
Average lenght of eutectic silicon [µm]	16,20±7,06	18,23±6,95	24,89±11,57

The micro-structured materials concept.

Experimental details

Melt./mould Temp.

Mechanical Properties



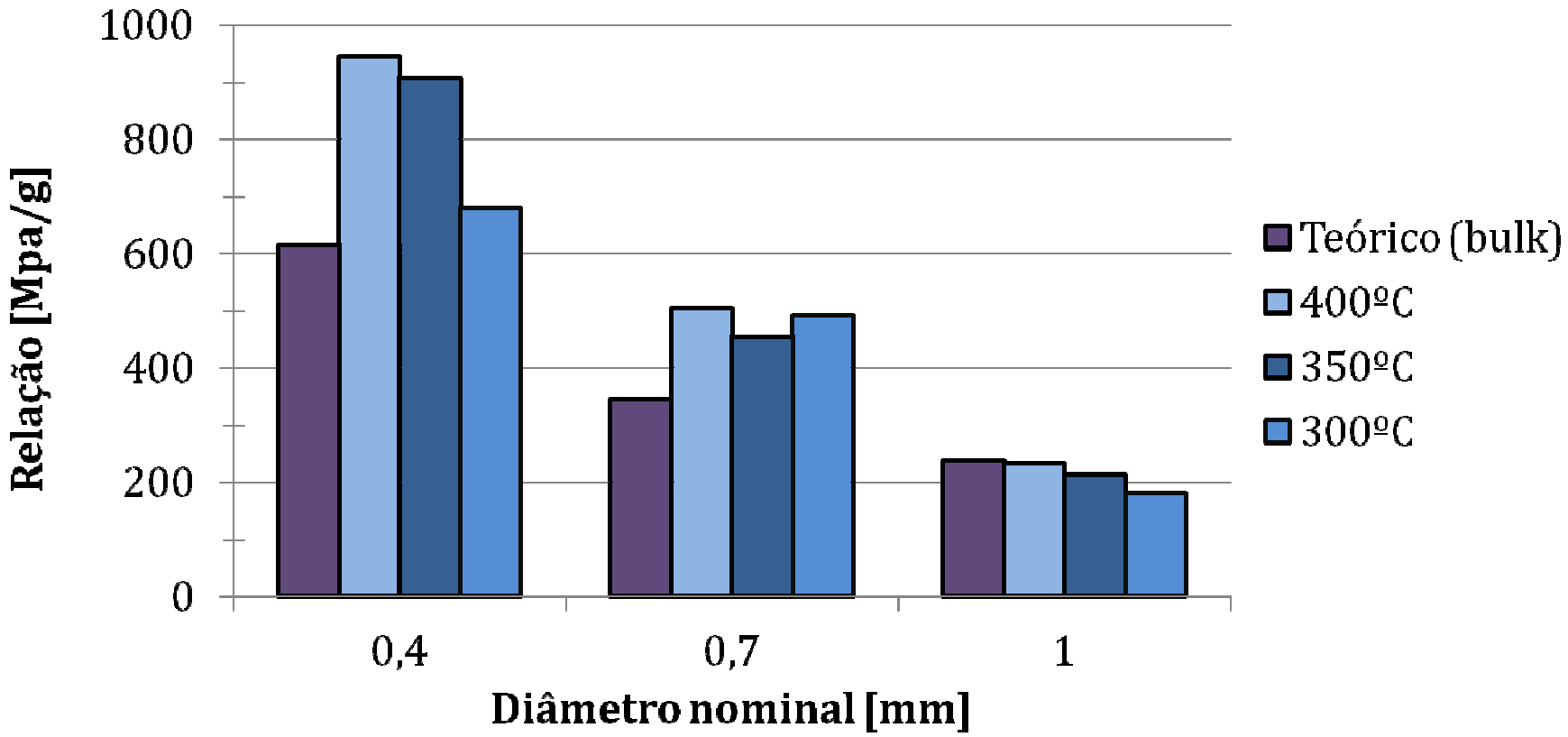
Rupture strenght for different mould temperature and different nominal diamater

The micro-structured materials concept.

Experimental details

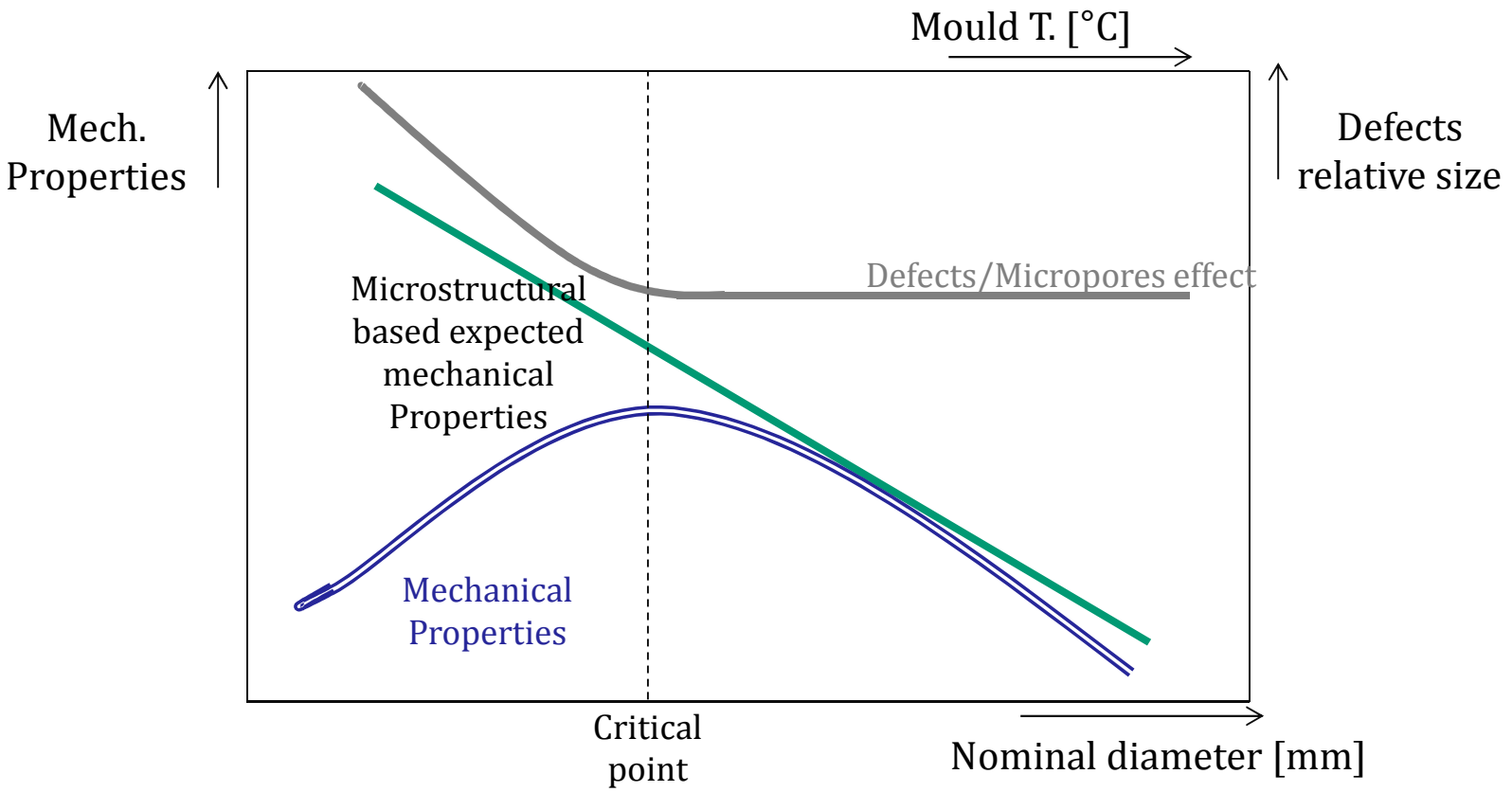
Melt./mould Temp.

Specific mechanical properties *(Rupture strenght/weight)*



Relationship mechanical properties (Rupture trenght/weight) for different nominal diamaters.

Evaluation of relative influence of different processing parameters



The micro-structured materials concept.

Experimental details

Vibration (filling)

Roughness

Both variables (roughness and vibration during filling) interfere with heat transfer

The micro-structured materials concept.

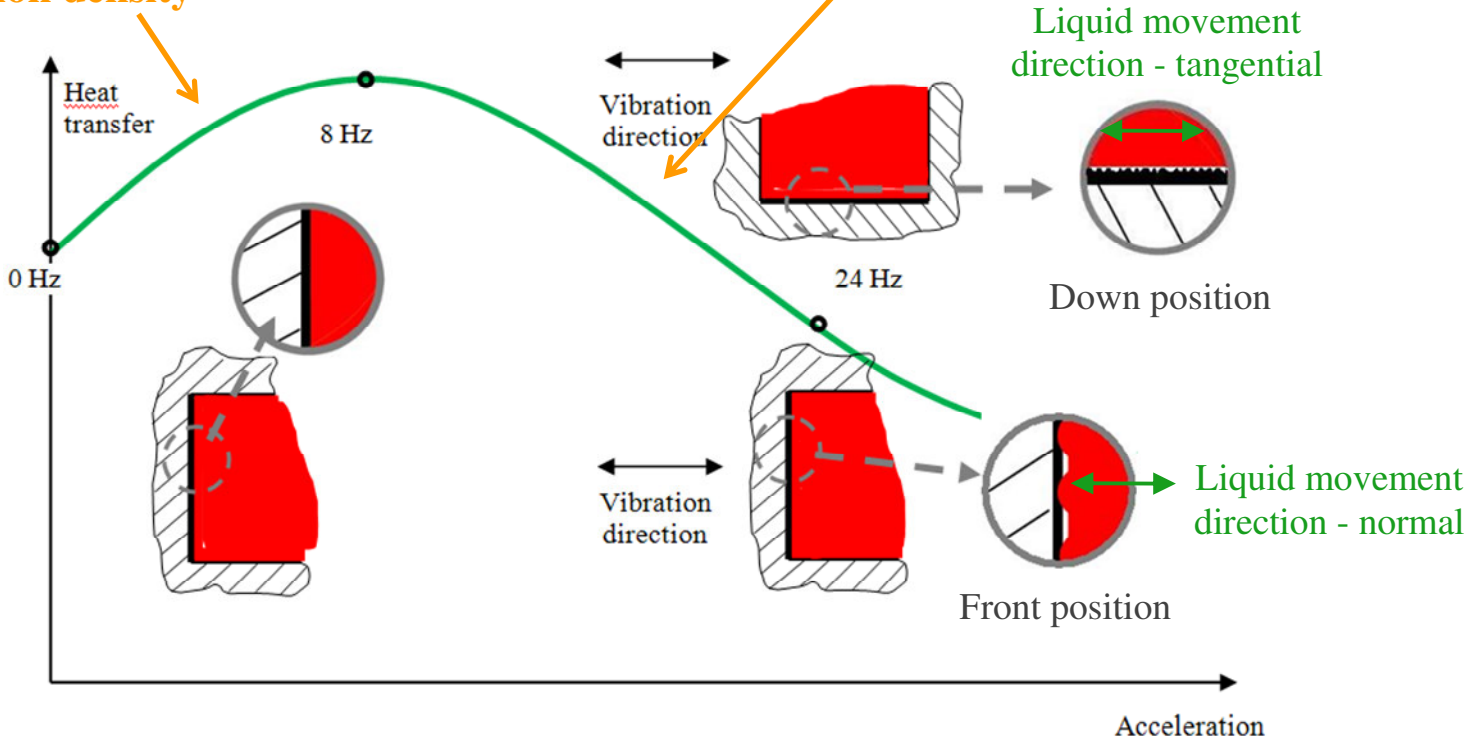
Experimental details

Vibration (filling)

- **Mould vibration during pouring may help on filling;**

- **Mechanism – conductive heat transfer due to liquid movement and nucleation density**

- **Mechanism – interface loss of contact – conductive and convective heat transfer**



Schematic representation of heat transfer mechanism with vibration

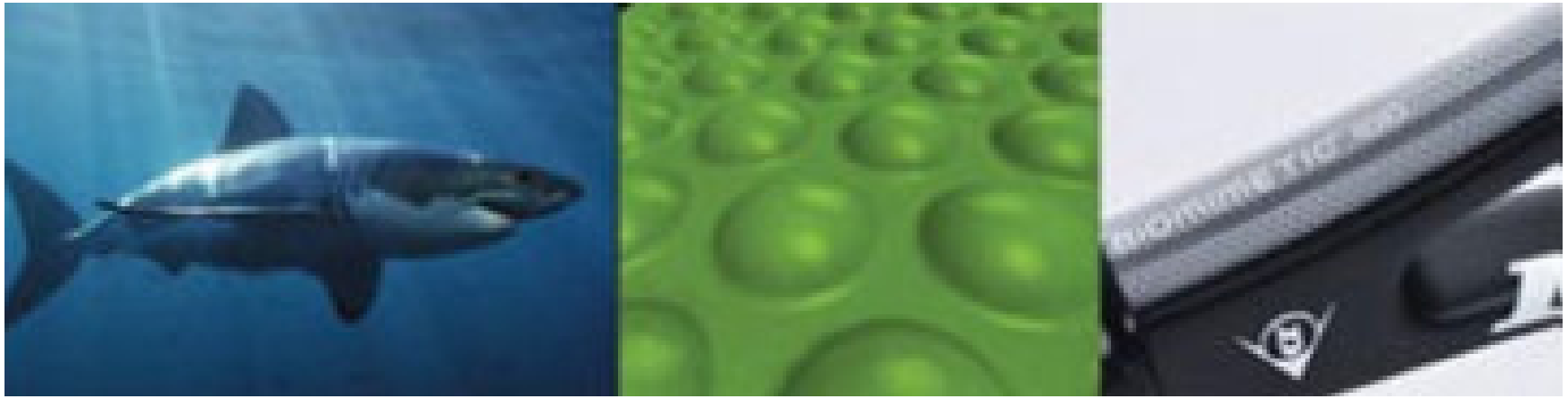
The micro-structured materials concept.

Experimental details

Roughness

- **Roughness of pieces may help on filling;**

Learning from nature



Shark skin mimic in the Biomimetic Dunlop racket

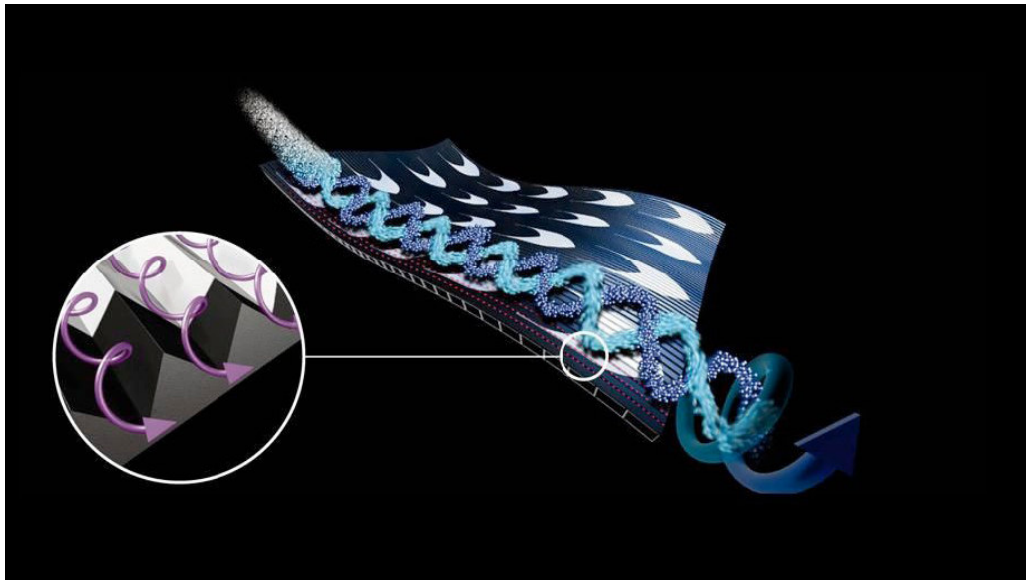
reduces contact betweem liquid and solid

The micro-structured materials concept.

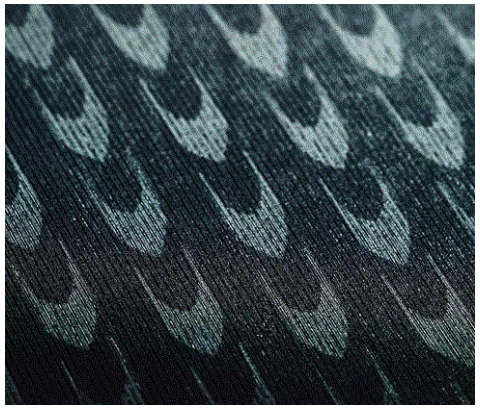
Experimental details

Roughness

- **Roughness of pieces may help on filling;**



Learning from nature



Speedo fabric

reduces contact betweem liquid and solid

The micro-structured materials concept.

Experimental details

Roughness

- **Roughness of pieces may help on filling;**

Hydrophobic surface

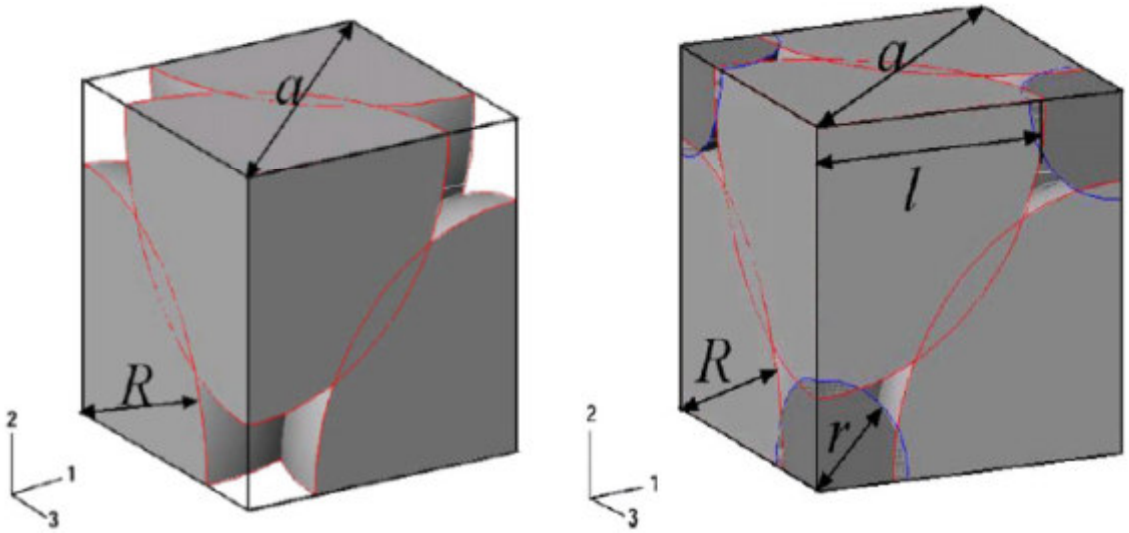
reduces contact betweem liquid and solid

The micro-structured materials concept.

Experimental details

Structural design

Internal Structural design strongly influences mechanical properties;

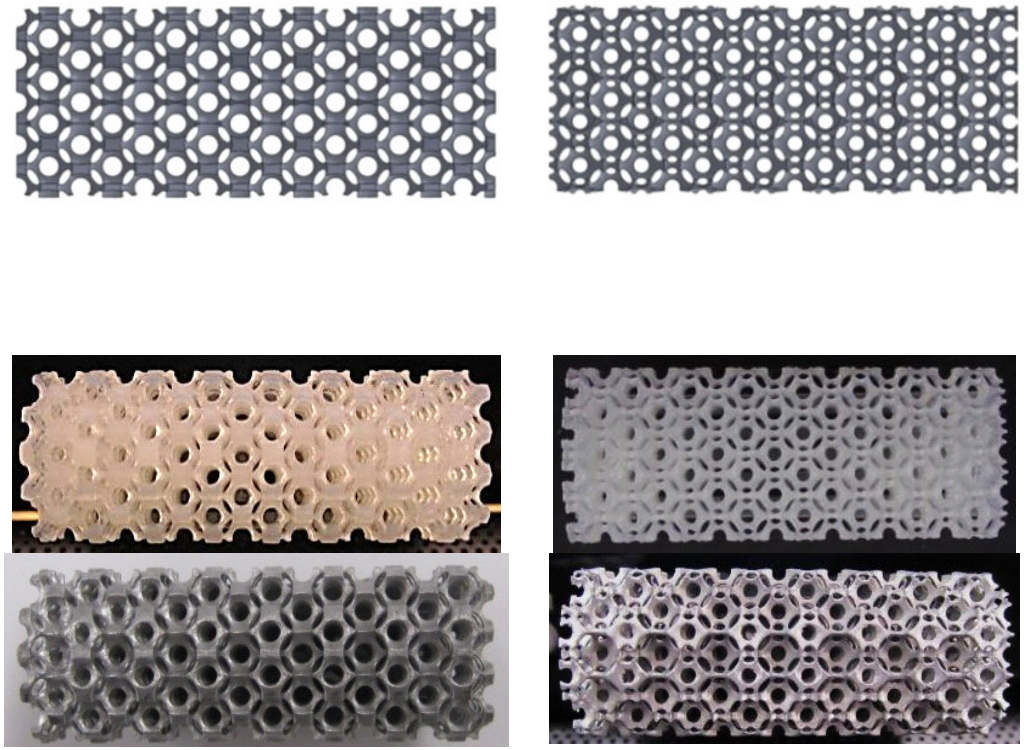


Compacted structures of fillers in open-cell arrangements, left: uniform-size structure; right: dual-size structure.

The micro-structured materials concept.

Experimental details

Structural design



a b

Compacted structures of fillers in open-cell arrangements, left: uniform-size structure; right: dual-size structure.

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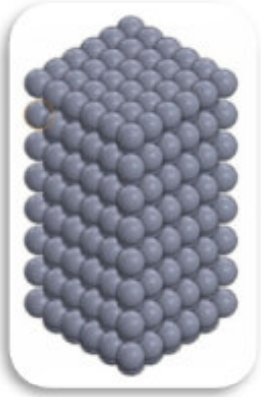
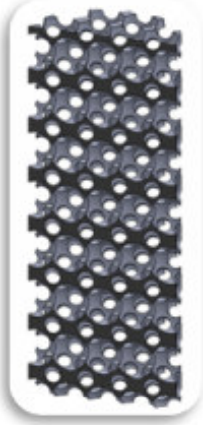
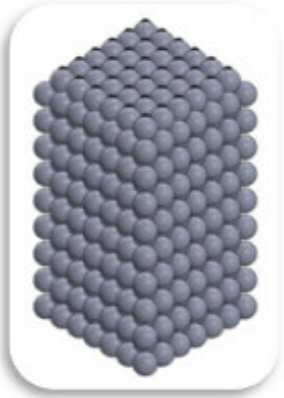
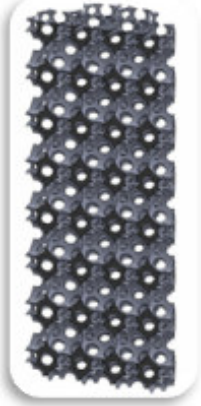
The micro-structured materials concept.

Experimental details

Structural design

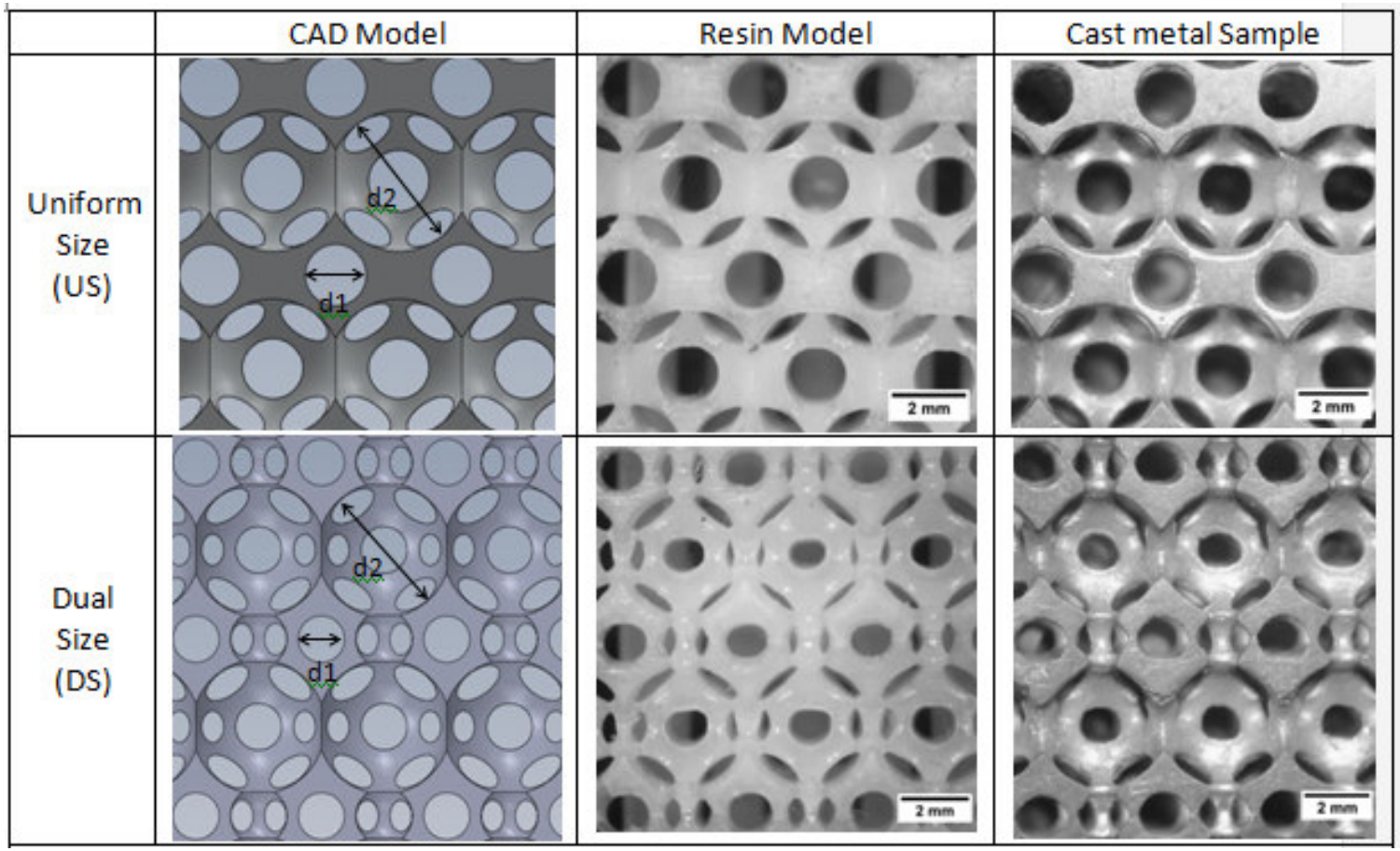
Uniform-Size			
	X.a1	X.b1	X.c1
Dual-Size			
	X.a2	X.b2	X.c2

Compacted structures of fillers in open-cell arrangements, left: uniform-size structure; right: dual-size structure.

The micro-structured materials concept.

Experimental details

Structural design



Geometry evolution from CAD to cast piece

The micro-structured materials concept.

Experimental details

Structural design

Compressive tests

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The micro-structured materials concept.

Experimental details

Structural design

Specimen	mass (g)	$P_{máx}$ (N)	Specific $P_{máx}$ (N/g)	Stiffness (N/m)	Specific Stiffness (N/m.g)
US 1	3,23	744,9	230,6	10,7E+05	3,31E+05
US 2	3,27	662,3	202,5	8,99E+05	2,75E+05
US 3	3,02	660,4	218,7	7,20E+05	2,38E+05
US 4	3,07	716,1	233,2	9,43E+05	3,07E+05
Average		695,9	221,3	9,09E+05	2,88E+05
Standard deviation		41,6	14,0	1,46E+05	0,40E+05
DS 1	3,32	1454,9	438,2	16,8E+05	5,06E+05
DS 2	2,83	1165,8	411,9	8,71E+05	3,08E+05
DS 3	2,91	1165,2	400,4	9,93E+05	3,41E+05
DS 4	3,00	1097,5	365,8	9,89E+05	3,30E+05
Average		1220,9	404,1	11,3E+05	3,71E+05
Standard deviation		159,3	30,0	3,71E+05	0,91E+05
Variation		+75.4%	**+82.6%**	+24.3%	**+28.8%**

Specific strength improvement

Internal Structural design strongly influences mechanical properties;

The micro-structured materials concept.

Conclusions

The micro-structured materials concept:

Seems to be feasible;

Seems to be a quick process;

No changes in relation to existing technologies;

The micro-structured materials concept.

Challenges

- **There are still some challenges;**

How to produce internal structures with traditional lost wax casting technique (wax and rubber);

Disinvestment;

???

Minho University
Guimarães
PORTUGAL

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www.ct2m.uminho.pt

Thanks to
JTF,
and to all of you

Filipe Samuel Silva
Departamento de Engenharia Mecânica www.dem.uminho.pt
Campus de Azurém, 4800-058 Guimarães - PORTUGAL
Tel.:+351253510732; Fax.: +351253516007; Tlm.: +351917560788; Email: fsamuel@dem.uminho.pt