Digital Manufacturing Master Degree to set specialists for the dawn of the Industry 4.0

Rapid Tooling for competitive AM

Co-funded by the Erasmus+ Programme of the European Union

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Learning outcomes: On successful completion of this module a student should be able to:

- Obtain advanced knowledge and good understanding of the theory, principles and applicability of: different RT techniques: Silicone rubber moulding, Metal spray tooling for injection moulding, Investment casting, Selective Laser Sintering, Selective Laser Melting, etc.;
- Discuss and select the appropriate RT methods, which should take advantage of the master models made by 3D printing;
- Explain the competitive industrial applications of AM;
- Describe the main factors which have significant influence of the AM competitiveness and what are the main criteria to select he appropriate tooling route (volume production, type of material, complexity of the part, etc.).

Course purpose:

- The purpose of the course is to ensure the accumulation of technical competences on how to make AM more competitive for industrial production.
- The course deals with aspects related to Rapid Tooling (RT), which are innovative technologies working with master models made by AM, which are further used for low and medium volume production of complex parts, made from different materials (plastics, metals, composite materials, etc.).

Objectives of the course:

- Understand the principles of when and how AM could be a competitive technology for industrial production, not only an interesting method within the research laboratories
- Learn the basic Rapid Tooling methods and industrial applications of the patterns made by 3D printing
- Understand the principles of direct and indirect RT methods
- Select the appropriate RT techniques for specific industrial or medical applications of AM

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Professional competences:

- Evaluate the specific productions requirements (e.g. volume production, type of material, complexity of the part), in order to select the suitable AM process to print the master model;
- Investigate, which are the available RT techniques, suitable to use the master model (printed from a simulant material), in order to get a low volume production of the parts, made from final material;
- Evaluate the possibilities of using AM in Rapid Product Development, where functional tests of the new product are required and the complex parts have to be made from final materials;
- Design the appropriate RT technology, select the splitting line, gating, venting for vacuum casting, investment casting, metal spray tooling, etc.;
- Coordinate the tasks distribution between the operators according to the work plan as well as manage the links between them.

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Transversal competences:

- Interacting and working with others and team members to accomplish team goals and strategies;
- Contributing ideas, solutions, and efforts in a group work or project;
- Making decisions and solving problems respecting the team consensus. Ensuring that all the decisions are made according to the policies and rules. Solving the emerging problems in the work;
- Working in multidisciplinary team of people with variety of skills, knowledge, and backgrounds. Actively participating and collaborating with team members in order to get better ideas and solutions.

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Content of the course:

- Moving AM from research laboratories to industrial production
  - Design for AM and virtual prototyping
  - Transferring the CAD model to the AM machines
  - The need and importance of AM for RPD
  - How to select the adequate AM method, for specific applications
- Vacuum Casting by SRM (Silicone Rubber Molding)
  - How does SRM works?
  - How to cast parts into SRM?
- Investment casting of metal parts and applications
- Rapid tooling by SLM
  - Steps and procedure in the SLM process
  - Simulation of SLM process
  - Technological parameters
  - Heat treatment for stress releasing
  - Supports removal and finishing the SLM parts

AM and RT for Rapid Product Development:

- Introduction to Innovative Manufacturing
- Experimental case studies of manufacturing complex metal parts
  - selective laser melting (SLM)
  - selective laser sintering (SLS)
  - CNC milling
- Evaluate the benefits, using different criteria
  - dimensional accuracy
  - surface roughness
  - manufacturing time and costs

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RAPID TOOLING PROCESS SELECTION: plastic parts

Plastic parts	Production material	Simulant
1 off	Not cost effective	FDM – ABS / SL – Epoxy resin SLS - Duraform
10 off	AIM tooling Ceramic cast tooling Sprayed metal tooling (Zinc)	Vacuum Casting Thin RIM moulding RP parts
100 off	AIM tooling Spray metal tooling (steel) Resin Cast Tooling Laser sintered tools	RIM moulding
1,000 parts	Laser sintered tools Cast aluminium tooling 3D - Keltool	Not cost effective
10,000 parts +	Laser sintered tooling Electroformed tooling Investment cast tools (steel)	Not cost effective

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RAPID TOOLING PROCESS SELECTION: metal parts

Metal parts	Production material	Simulant
1 off	Investment cast from SLA, SLS, FDM Sand casting from RP patterns	Laser sintered metals
10 off	Investment cast from SLA, SLS, FDM Sand casting from RP patterns	Spin casting Laser sintered metals
100 off	Investment cast from waxes produced in RP cavities	Spin casting
1,000 parts	Die casting into Keltool Die casting into laminated tools	Not cost effective
10,000 parts +	Die casting into Keltool Die casting into laminated tools Investment cast steel dies	Not cost effective

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Vacuum casting for low volume production of the plastic parts

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Vacuum casting for low volume production of the plastic parts

DIGIMAN
master programme for digital manufacturing

1. 3D Model
2. Master model, made using AM technologies
3. Support removal and preparing the model
4. Establishing the separation plan
5. Building the box and fixing the master model
6. Mixing silicone rubber with curing binder and degassing
7. Casting silicone in the box and 2nd degassing
8. Curing of silicone rubber
9. Extracting the master model

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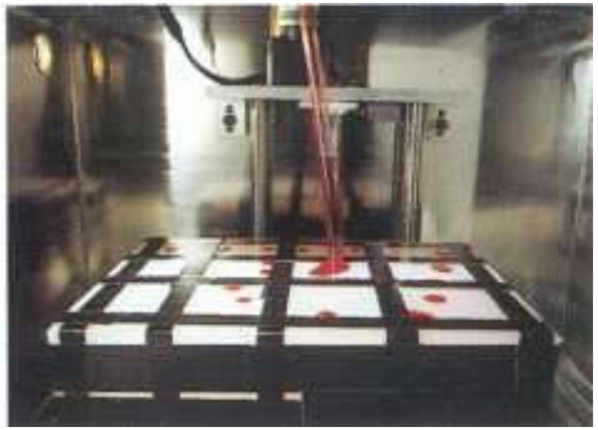
Vacuum Casting Process



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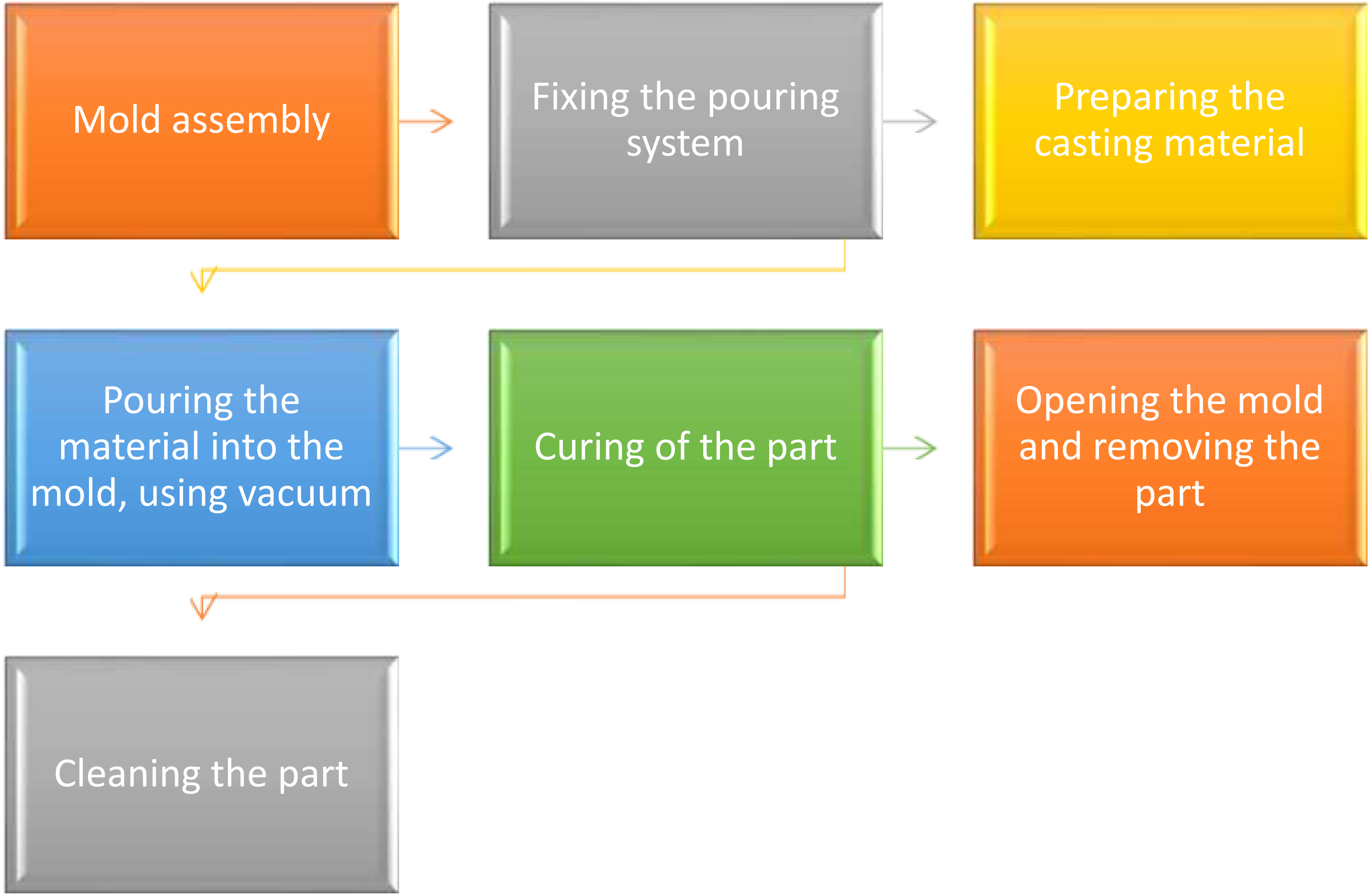
Vacuum Casting Process



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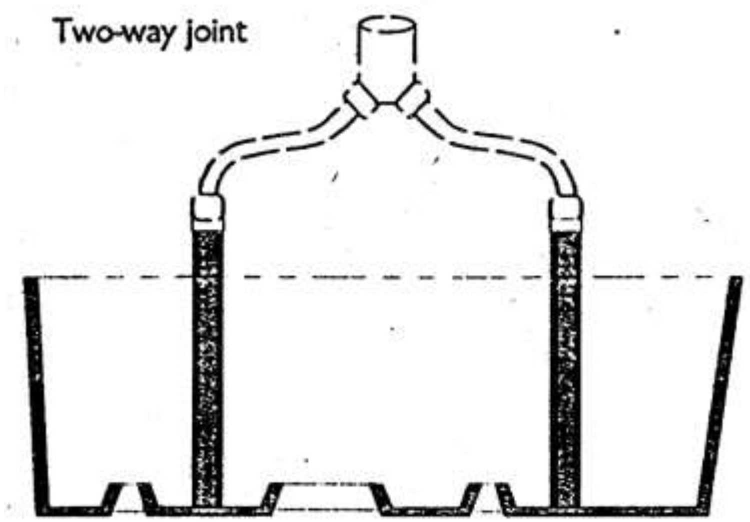
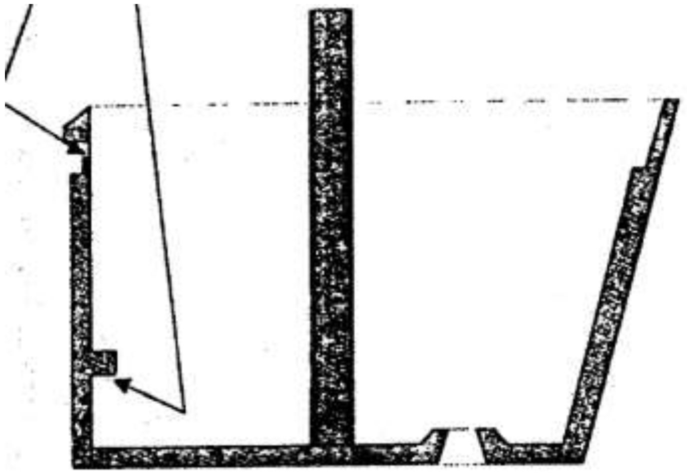
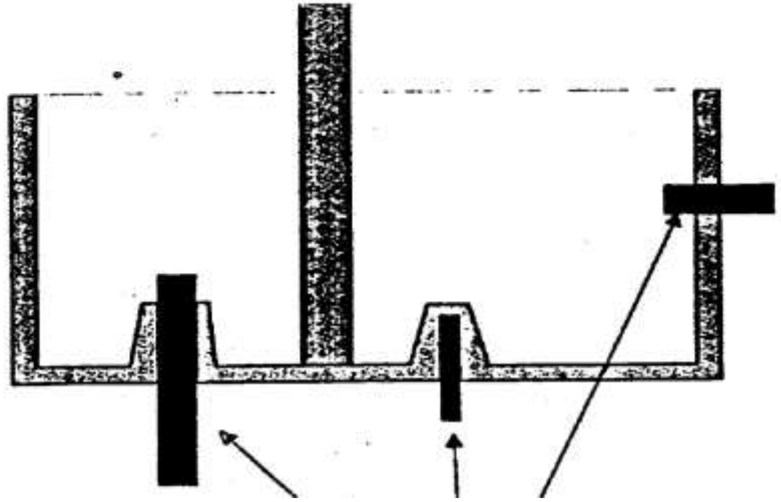
Gating, undercuts, inserts







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IC - Investment Casting process, versus Die Casting

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1. Wax patterns manufacturing
2. Wax tree assembly
3. Ceramic mold manufacturing
4. Drying the ceramic form in the oven and removing the wax
5. Preparing the metal for casting
6. Casting the metal in ceramic form
7. Removing the mold using water under pressure
8. Cutting and finishing of metal parts

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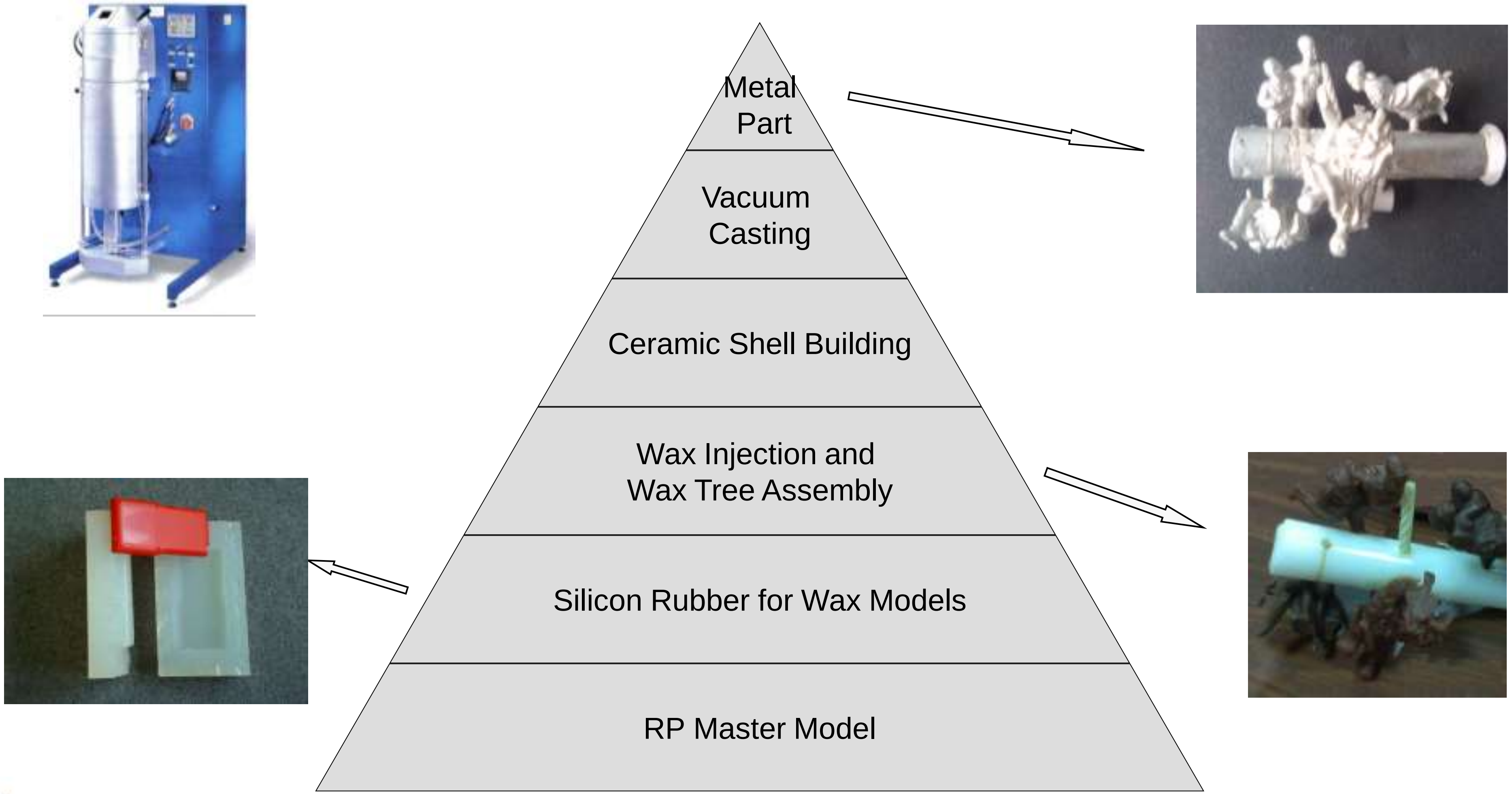
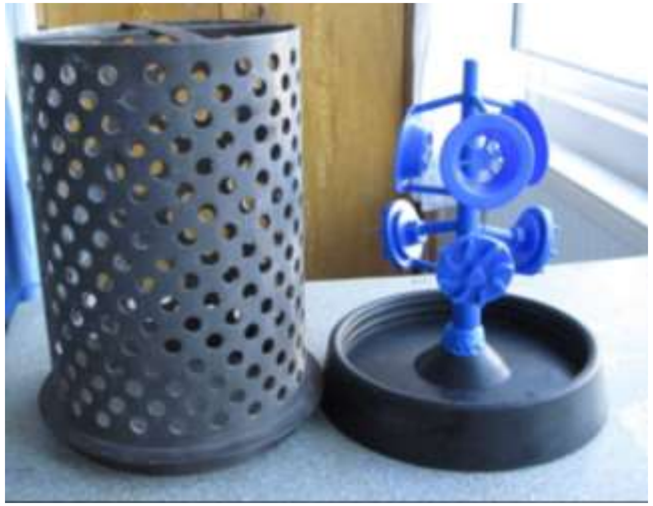
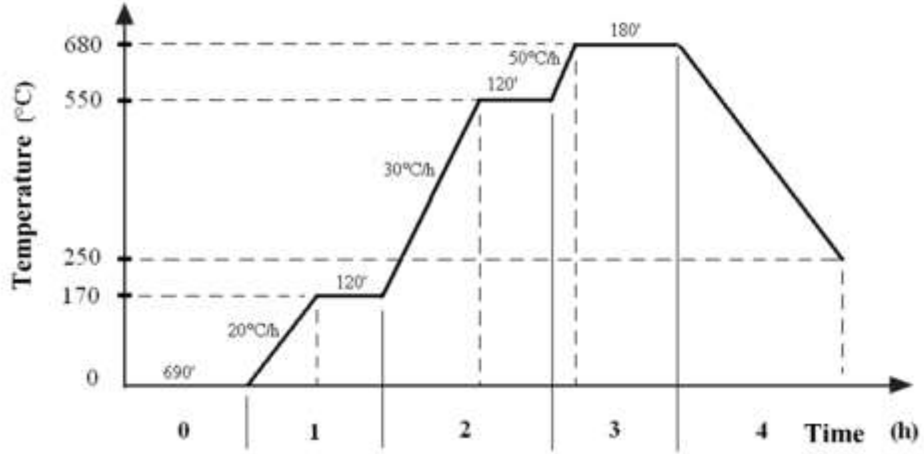
Investment Casting process

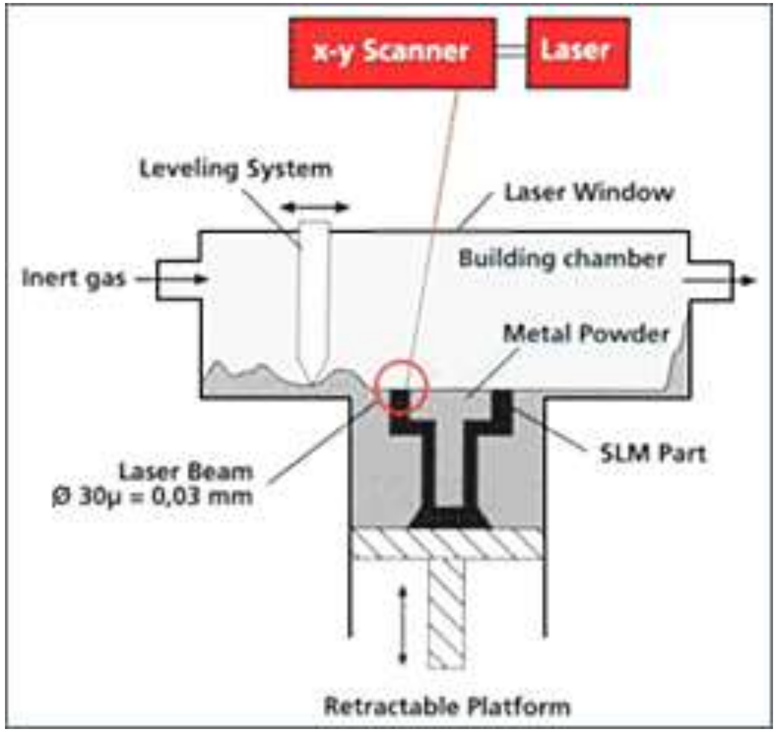


Investment Casting process

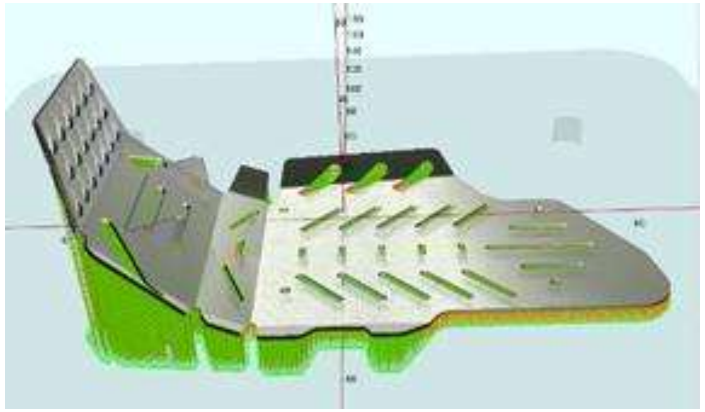


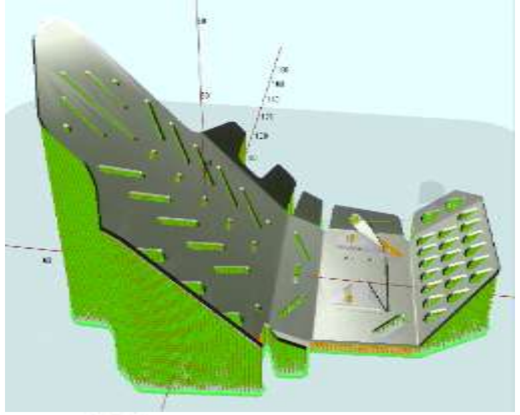


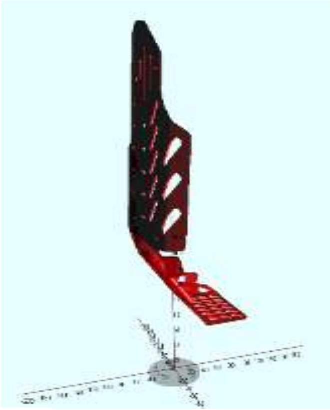
Selective Laser Melting (SLM) at the TU of Cluj

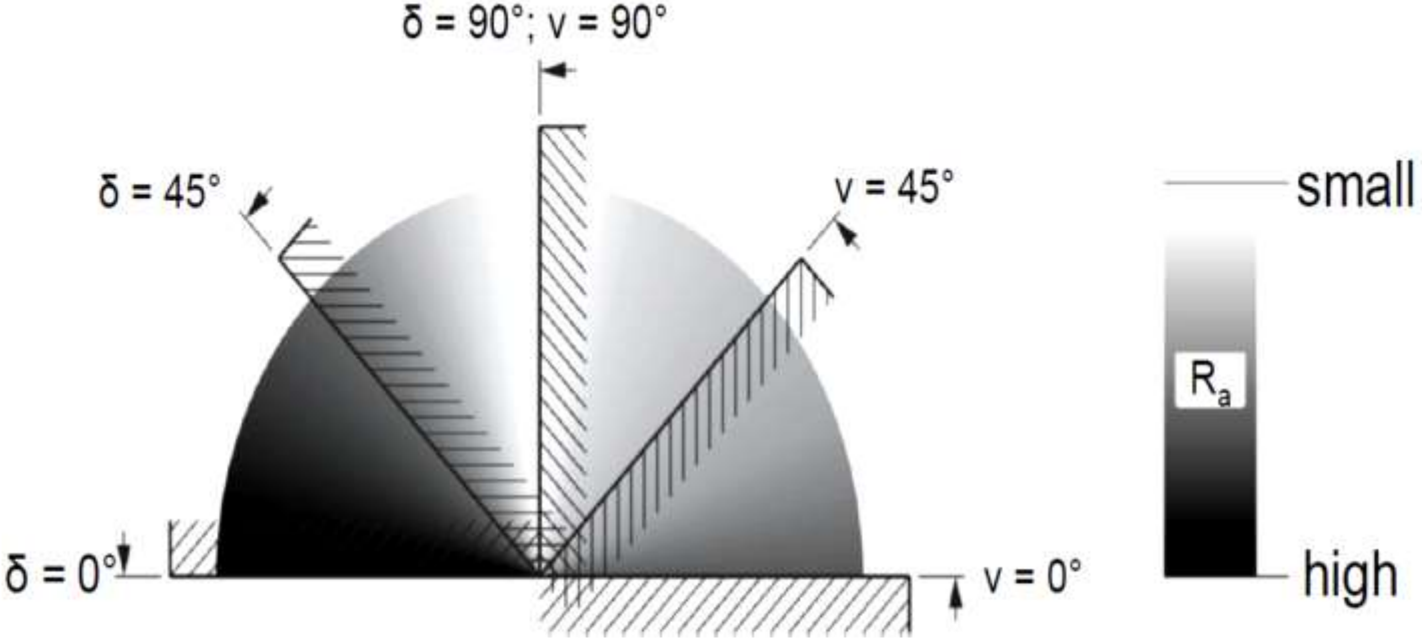


Part orientation: Influence of the build-up angle - Ra









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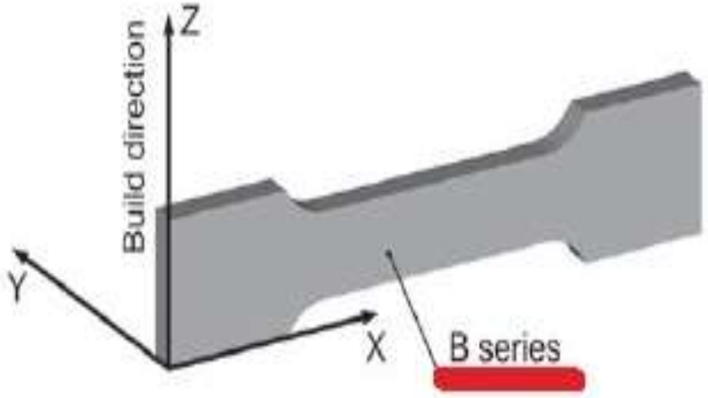
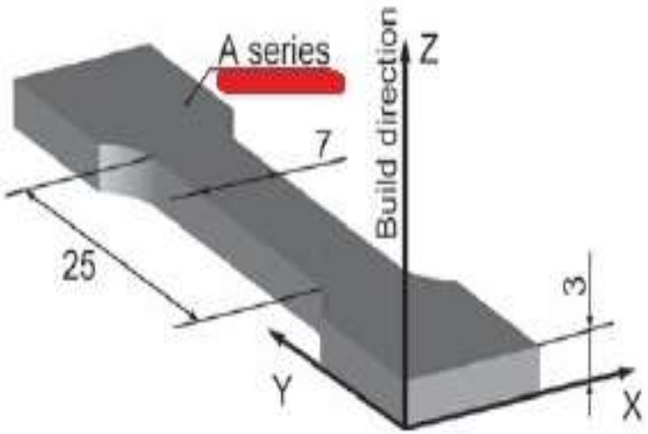
Influence of build-up orientation on ultimate tensile strength





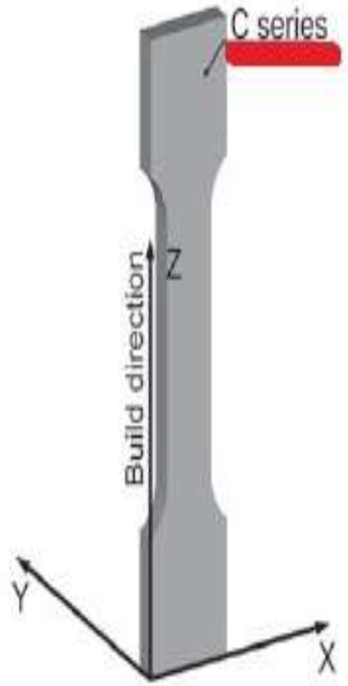
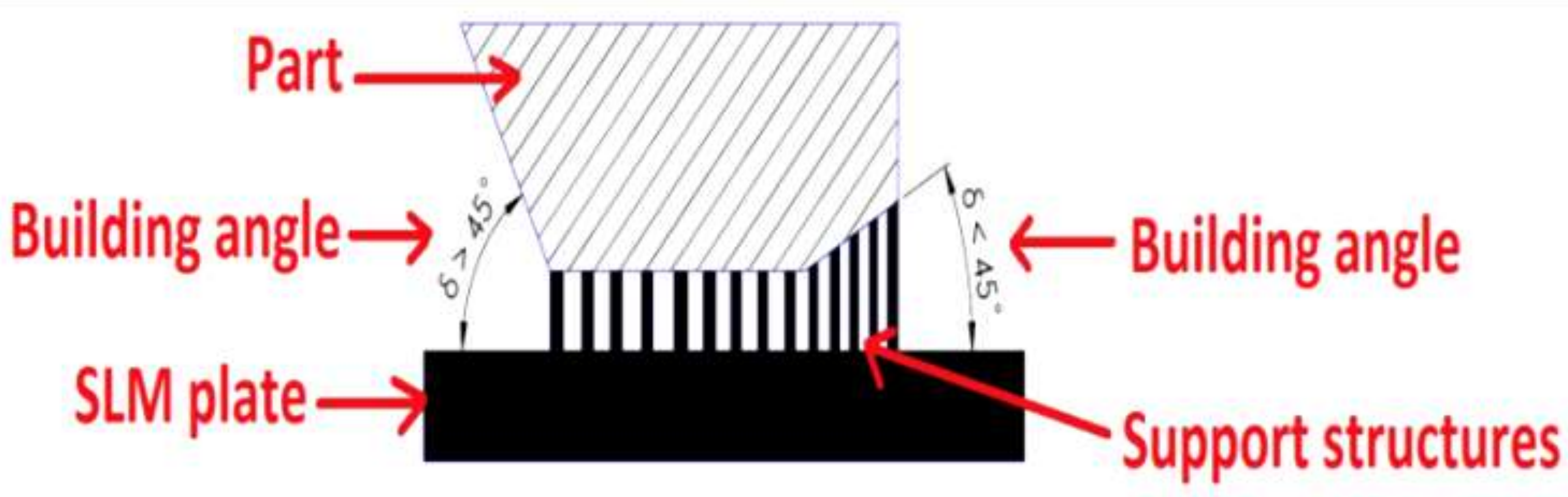
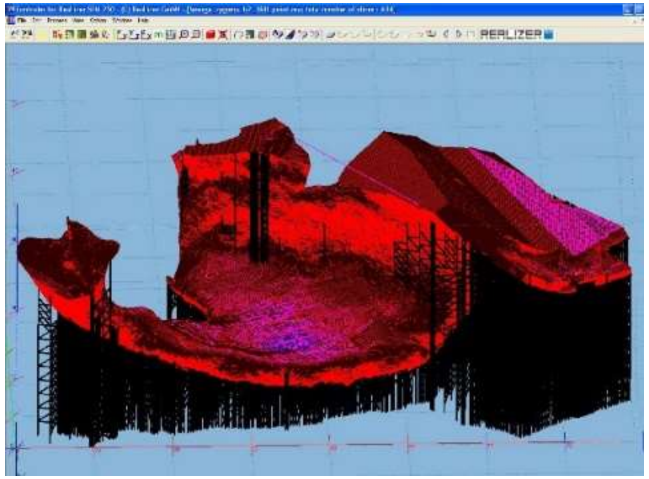


Table - Results of mechanical tests on the as-built Ti6Al—7Nb alloy.

Build direction	$\sigma_{0.2}$ MPa	σ_t MPa	E GPa
A series	1440±59	1515±60	88±2
B series	1360±30	1480±26	88±3
C series	–	776±40	121±14

Support structures needed to anchor surfaces





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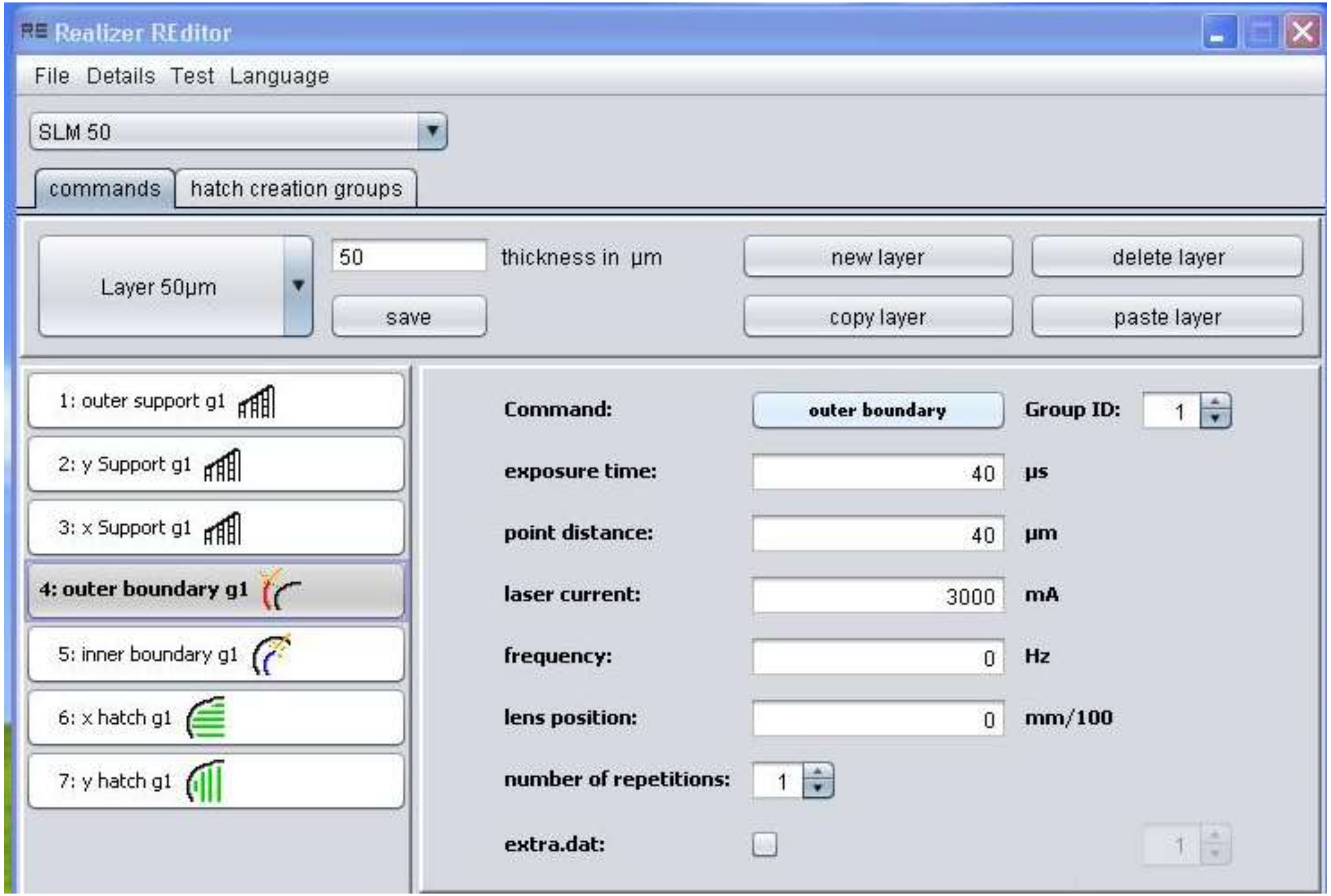
SLM process parameters: Outer-boundary function



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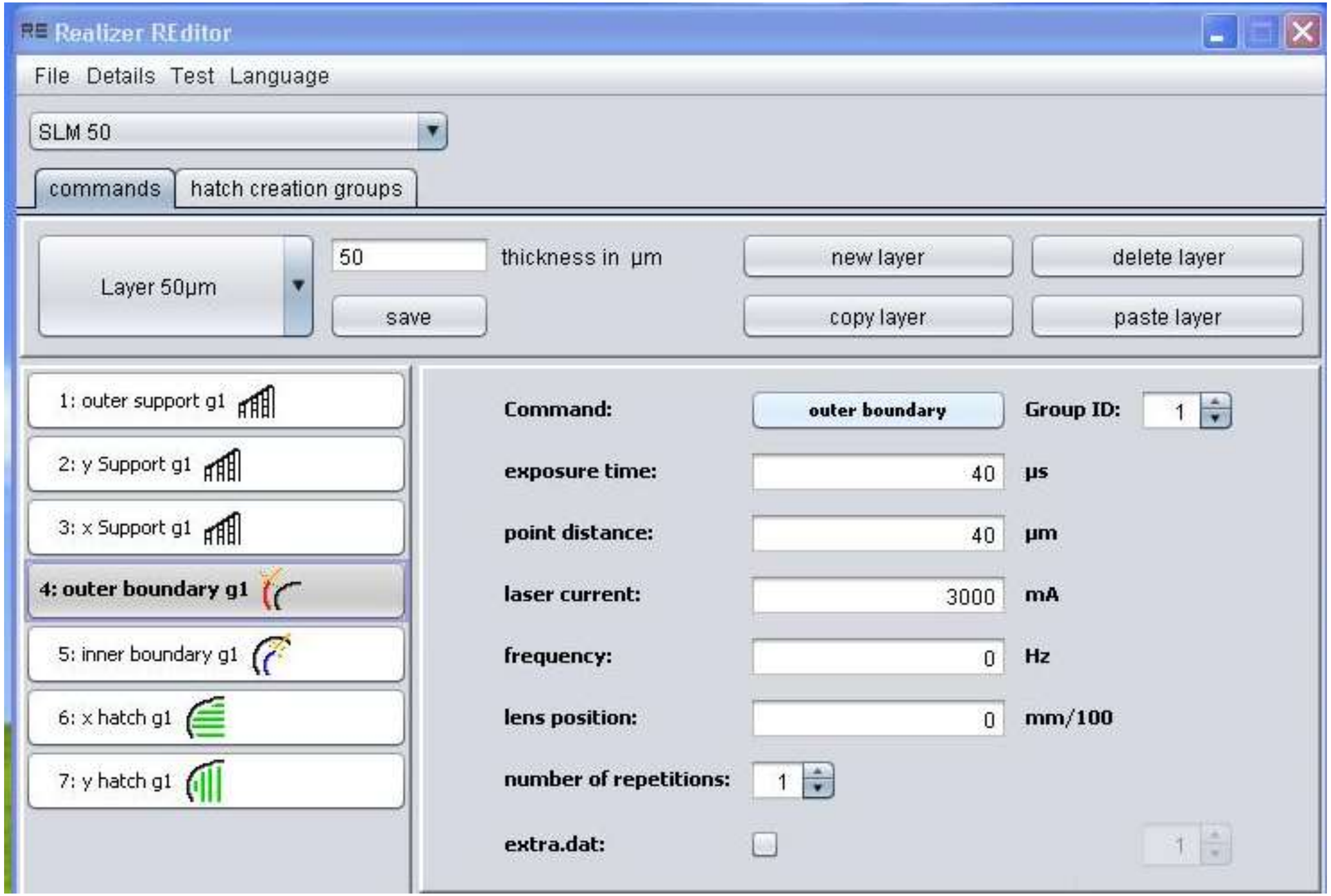
SLM process parameters: Hatch function for scanning in X direction



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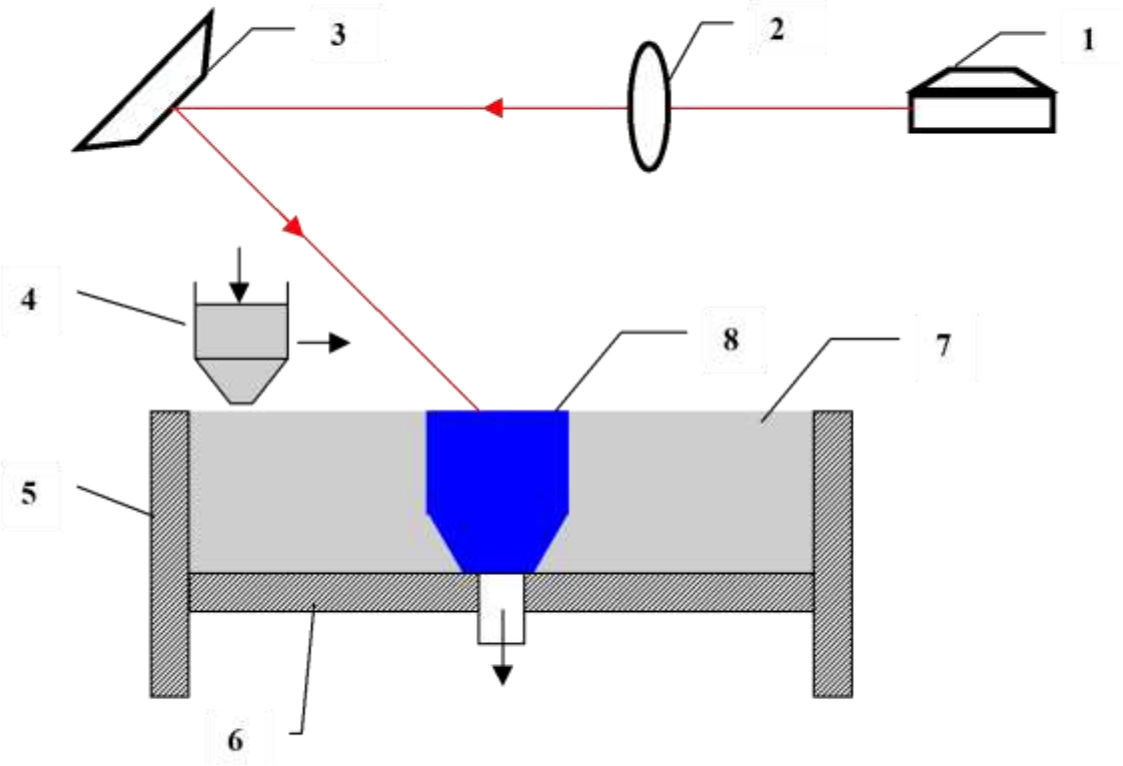
Selective Laser Sintering (SLM) at the TU of Cluj



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Comparison between SLM - SLS and CNC

- SLM technology is suitable to obtain fully dense metal parts
  - if the required accuracy is not high
  - The manufacturing costs are higher, as compare to similar CNC
- The are still future research needs to be done in order to improve the accuracy on the SLS/SLM
- Rapid Tooling by SLS could become a quick solution for tool makers, when dealing with rapid product development and with low volume production of the complex plastic parts

Comparison and limitations:

- Additive manufacturing isn't a solution to every part fabrication problem
  - After all, CNC technology is economical, widely understood and available, offers wide material selection and excellent accuracy
  - However, if the requirement involves producing a part or object of even moderately complex geometry, and doing so quickly – RP&T has the advantage
- The materials used in AM are limited
  - dependent on the method chosen ,
  - however, the range and properties available are growing quickly ,
  - plastics, ceramics, metals ranging from stainless steel to titanium, and wood-like paper are available

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