Utilization of In-situ Resources and Transported Materials for Infrastructure and Hardware Manufacturing on the Moon – Ongoing Developments by ESA Materials Scientists

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Introduction

• **Materials** are key aspects in the design of missions for exploration and the establishment of **sustainable** settlements on the Moon (or Mars)

• **Maximise** the use of Material resources available at destination
  - Substantial **savings** in payload **mass, cost** and mission **complexity**
  - **Reduce dependence** on cargo

• **In-situ Resource Utilisation** (ISRU) for building of habitat and supporting structures (e.g. landing pads, shielding walls, antenna towers...)
  - Enables establishment and expansion of settlement
  - Various technologies investigated
Introduction

• **Optimum usage, re-use and recycling** of Materials brought for the mission – in particular **functional polymers** – for the production and the recycling of hardware for maintenance of infrastructure and equipment
  
  ➤ Careful Material selection during mission design phases: re-usable, recyclable
  
  ➤ Versatile materials and processes to increase maintenance capability
  
  ➤ Achieve sustainable settlement: reduce Material waste

• **Additive Manufacturing** (AM) techniques are of high interest as they allow efficient material use, do not require cutting, joining tools and can be automated
  
  ➤ **Enabling** technologies
Introduction

This presentation gives an **overview of relevant activities** supported by and/or conducted within the European Space Research and Technology Center’s **TEC-QT division (Components Technology & Space Materials)**

For these activities, collaboration exists with the European Astronaut Centre’s Spaceship EAC’s initiative

Spaceship EAC investigates low TRL concepts at an early stage, to address different building blocks of a Human settlement – Moon Village

ESTEC’s TEC-QT supports the development of technical solutions allowing the processing Materials in a system perspective

Some commonalities exist between the two ESA establishments and frequent exchanges allow maximising cross benefits of this collaboration and minimising overlaps
In-Situ Resource Utilisation

- Abundant resource to produce construction material for infrastructure and hardware manufacturing: regolith

- Various technologies are investigated to turn regolith into building material
3D Printing of Lunar Base Building Block Using a Mg-based Binder (D-Shape process)

• ESA-funded study (General Studies Programme) 2012
• Consortium: Monolite (UK, printing technology), Alta (Italy, space industry), Scuola Superiore Sant’Anna (Italy, process control), Foster+Partners (UK, architects)

• 3D printing technology: D-Shape process: mix the lunar regolith with a MgO/ MgCl₂ binder
• Development of a regolith simulant (DNA)
• Printing experiments under vacuum
3D Printing of Lunar Base Building Block Using a Mg-based Binder (D-Shape process)

- Design of Lunar base concept
- 1.5 ton Lunar base building block demonstrator

**Challenges:**

- Binder
- Regolith behaviour (abrasive, charged, radiation)
- Mobility (rover)
3D Printing of Lunar Base Building Block by Solar Sintering

• ESA-funded study (General Support Technology Programme): 2015 –
• Contractor: DLR (DE)
• 3D printing technology: solar sintering using concentrated solar light
  ➫ No binder brought from Earth, use of local energy source
• Design of 3D printing equipment and process (Xe high-flux solar simulator)
3D Printing of Lunar Base Building Block by Solar Sintering

- Study of scanning strategy and effect on printed material structure
- Characterisation of regolith and sintered material
- **Challenges:**
  - Thermal stresses
  - Regolith behaviour (abrasive, charged, radiation)
  - Effect of vacuum

Sintered brick: 240x120x30 mm³
JSC-2A regolith simulant
Sintering Time: 5h30. Layer thickness ≈ 0.1 mm

145x65x40 mm³
JSC-2A regolith simulant
Limited Resources Manufacturing

- ESA-funded study (Basic Technology Research Programme): 2015 –
- Contractor: Fotec (AT)
- Mapping and trade-off of ISRU technologies for hardware manufacturing
- Programming of tool for technology trade-off using weighted criteria

Extrusion-deposition process diagram

Full map of process diagrams

Example of trade-off
Limited Resources Manufacturing

- Selection and demonstration of hardware manufacturing process:
  - Extrusion-deposition of regolith-based paste
  - Binder: concentrated phosphoric acid
  - Martian Regolith Simulant used, but process adaptable to Lunar Regolith

- Challenges: binder ratio, stickiness of paste

Early trials of extrusion of paste produced from concentrated phosphoric acid and JSC Mars-1a Martian regolith simulant. Acid:Regolith simulant ratio: left: 0.6:1; right 1:1. Process is being optimised to minimise ratio.
Usage and Recycling of Transported Materials for Hardware Manufacturing

• Use of available materials to manufacture hardware for maintenance of infrastructure and equipment

• Materials need to be recyclable:
  - To be turned into new hardware when needed ⇒ increased maintenance capability
  - To reduce waste ⇒ sustainable settlement

• Polymers:
  - Recyclable
  - Low melting point ⇒ lower energy required for melting
  - Can be functionalised (e.g. conductive) ⇒ address multiple maintenance needs
3D Printing with Engineering Thermoplastics

• Poly(ether ether ketone) - PEEK
• Thermal stability: $T_m = 343^\circ C$
• Mechanical Pties: $\sigma_{\text{tensile}} = 100$ Mpa, $E = 3.8$ Gpa
• 3D printing technique: fused filament fabrication

• Study of mechanical properties and internal structure for various build orientations:
  • 80 % of theoretical mechanical properties achieved for XY orientation
  • Thermo-chemical property consistency with raw material
  • Higher porosity and lower mechanical properties in Z direction
  • Process modification needed to improve interlayer adhesion
3D Printing with Engineering Thermoplastics

• ESA - General Support Technology Programme project:
  • Production of conductive engineering thermoplastics based of graphene technology
    ➔ Plastics as electrical conductor
    ➔ Running phase: 1st Q-2016 to 3rd Q-2016

• ESA – Networking and Partnering Initiative project:
  • Development of multifunctional engineering thermoplastics
    ➔ Running phase: 2015 to 2017
In-Orbit 3D Printing

• ESA - Basic Technology Research Programme project MELT:
• Breadboard development for in-orbit demonstration of additive layer manufacturing technologies
  ✔ Contractors: OHB/Active Space Technology/BEEVERYCREATIVE
  ✔ Zero G - Engineering thermoplastics - High aspect ratio
  ✔ Running phase: 3rd Q-2015 to 4th Q-2017

THERMOPLASTICS AND STRUCTURES
THERMOPLASTICS AND FUNCTIONAL PART
Future?

ON-THE-MOON AND ON-PLANET 3D PRINTING

MATERIALS
RECYCLING
ISRU
ROBOTISATION
UPSCALING

INCREASED MANUFACTURING CAPABILITIES REGARDING SIZE AND FUNCTIONALITY
Conclusions

• **Materials** aspects need to be part of a **system-level** view at the **early stages** of conceiving Moon missions for exploration and Human settlement
  • Selection of transported materials for re-use and recycling
  • Consideration of ISRU (required equipment, energy needs, mission location)

• **Additive Manufacturing** technologies are enabling elements for the establishment of **sustainable** Human settlements

• Various technologies for Material utilisation exist or are being developed
  ➔ **Combination** of several **technologies** for various purposes (infrastructure, hardware, large scale, small objects) should be combined in order to make full use of the available Materials to achieve the missions objectives
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Thank you for your attention

Questions?