ESA Vision on Clean Steel Materials and Structures for Space

Dr. Tommaso Ghidini
Head of the Structures, Mechanisms and Materials Division
European Space Agency

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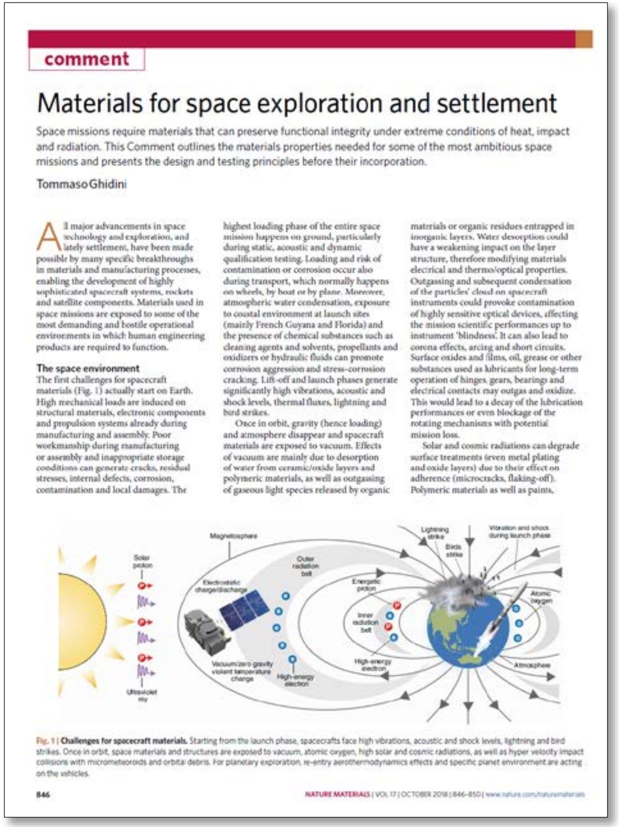
WE ARE ESA

EUROPE'S GATEWAY TO SPACE

WHAT	22 Member States, 5000 employees
WHY	Exploration and use of space for exclusively peaceful purposes
WHERE	HQ in Paris, 7 sites across Europe and a spaceport in French Guiana
HOW MUCH	€5.72 billion = €12 per European per year

Materials and Processes for Space Applications

- **The Space Environment:**
  - Most demanding and hostile operational environment for materials and structures
  - Space environment starts on Earth: Manufacturing / Assembly / Poor Workmanship / Inappropriate Storage / Corrosive Environment
  - Static / Acoustic / Dynamic Qualification Testing / Transport
  - Lift-Off and Launch Phases: High Vibrations / Acoustics / Shocks / Thermal Fluxes / Bird Strikes
  - On-Orbit/On-Planet: Vacuum / High Solar and Cosmic Radiations / Extreme Thermal Cycling and Local Thermal Conditions (e. g. Re-Entry, Planetary Specific) / Hyper-Velocity Impact (Micro-Meteroids / Space Debris) / Atomic Oxygen / Biological Treats (Manned Spaceflight / Planetary Specific Conditions)
  - Demisability
- **Space Materials and Processes Supply Chain Specific Challenges:**
  - Omnipresent need for low mass and low volume
  - Very High Performances / High Reliability with no repair/maintenance options
  - Small / Highly Complex Structures operating on highly demanding missions/environment
  - Small Production Series/Small Procurement volumes reducing the influence on supply chain, limiting availability of tailored materials and alloys and associated manufacturing processes
  - REACH/RoHs further restricting the already challenging supply chain



comment

Materials for space exploration and settlement

Space missions require materials that can preserve functional integrity under extreme conditions of heat, impact and radiation. This Comment outlines the materials properties needed for some of the most ambitious space missions and presents the design and testing principles before their incorporation.

Tommaso Ghidini

All major advancements in space technology and exploration, and lately settlement, have been made possible by many specific breaktheroughs in materials and manufacturing processes, enabling the development of highly sophisticated spacecraft systems, rockets and satellite components. Materials used in space missions are exposed to some of the most demanding and hostile operational environments in which human engineering products are required to function.

The space environment

The first challenges for spacecraft materials (Fig. 1) actually start on Earth. High mechanical loads are induced on structural materials, electronic components and propulsion systems already during manufacturing and assembly. Poor workmanship during manufacturing or assembly and inappropriate storage conditions can generate cracks, residual stresses, internal defects, corrosion, contamination and local damages. The highest loading phase of the entire space mission happens on ground, particularly during static, acoustic and dynamic qualification testing. Loading and risk of contamination or corrosion occur also during transport, which normally happens on wheels, by boat or by plane. Moreover, atmospheric water condensation, exposure to coastal environment at launch sites (mainly French Guyana and Florida) and the presence of chemical substances such as cleaning agents and solvents, propellants and oxidizers or hydraulic fluids can promote corrosion aggression and stress-corrosion cracking. Lift-off and launch phases generate significantly high vibrations, acoustic and shock levels, thermal fluxes, lightning and bird strikes.

Once in orbit, gravity (hence loading) and atmosphere disappear and spacecraft materials are exposed to vacuum. Effects of vacuum are mainly due to desorption of water from ceramic/oxide layers and polymeric materials, as well as outgassing of gaseous light species released by organic materials or organic residues entrapped in inorganic layers. Water desorption could have a weakening impact on the layer structure, therefore modifying materials electrical and thermo/optical properties. Outgassing and subsequent condensation of the particles' cloud on spacecraft instruments could provoke contamination of highly sensitive optical devices, affecting the mission scientific performances up to instrument 'blindness'. It can also lead to corona effects, arcing and short circuits. Surface oxides and films, oil, grease or other substances used as lubricants for long-term operation of hinges, gears, bearings and electrical contacts may outgas and oxidize. This would lead to a decay of the lubrication performances or even blockage of the rotating mechanisms with potential mission loss.

Solar and cosmic radiations can degrade surface treatments (even metal plating and oxide layers) due to their effect on adherence (microcracks, flaking-off). Polymeric materials as well as paints,

Fig. 1 | **Challenges for spacecraft materials.** Starting from the launch phase, spacecrafts face high vibrations, acoustic and shock levels, lightning and bird strikes. Once in orbit, space materials and structures are exposed to vacuum, atomic oxygen, high solar and cosmic radiations, as well as hyper velocity impact collisions with micrometeoroids and orbital debris. For planetary exploration, re-entry aerothermodynamics effects and specific planet environment are acting on the vehicles.

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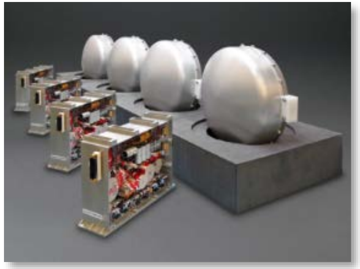
Stainless Steel for Space Applications

- **Mainly Used Steel/Stainless Steel and Their Applications:**
  - Austenitic: 304 and 316, general purpose, most commonly used, A286: High strength fasteners
  - Ferritic: 430 and 430F: good properties and easily machined, used on mechanisms
  - Martensitic: 440C, 15-5PH, 17-4PH: Bearings, gears, mechanisms where wear resistance is required
  - Nickel- and Cobalt-base super-alloys (e. g. Inconel 718 widely used on structural and propulsion systems applications)
  - Overall main applications: Propulsion systems, bearings, mechanisms, reaction wheels, actuators, tanks, structures, ground support equipment and ground structures

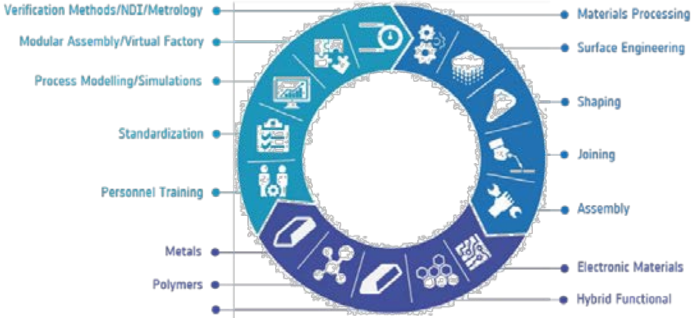


- **Current Industrial Landscape:**
  - Space was originally limited in terms production volumes, hence reducing the environmental footprint of space related manufacturing
  - **However:** Recently larger production volumes more and more required for satellite mega-constellations (particularly in the Navigation, Earth Observation and Telecommunication markets) and launchers manufacturing
  - **Opportunity:** Spinning-in technologies from larger manufacturing domains (e. g. aviation, automotive, etc.), maximizing Industry 4.0 cross-fertilization

ESA Clean Space and Advanced Manufacturing Initiatives

- **Clean Space and Advanced Manufacturing:**
  - ESA took the lead to reduce the Carbon-foot print of its space missions
  - Clean Space and Advanced Manufacturing Cross-Cutting Initiatives created in order to identify and mature for space applications “greener” materials and manufacturing processes ensuring same performances of the original “dirty” technologies
  - Showing the example as an Agency and fostering further buying-in effect
- **Strategic Lines of Actions:**
  - LCA (Life Cycle Assessment) issued for each space mission as well as each material/processes application
  - Citric Acid Passivation replacing Nitric Acid Passivation (carcinogenic)
  - Additive Manufacturing (reducing material used by 50 to 90%, hence reducing produced/transported/wasted/recycled material, reducing CO2 footprint)
  - Solid State Joining Technologies (reducing manufacturing steps, need for chemicals, reducing fumes, spattering, etc.)
  - Smart Manufacturing (optimising supply chain, reducing manufacturing steps, maintenance, consumables, etc.)
  - Virtual Storage (maximising products/consumables utilisation)
  - Systematic Recycle (Planetary Exploration – Settlement approach)

Advanced Manufacturing



Thank you for your attention!

tommaso.ghidini@esa.int
www.esa.int