Acronym: MSL-CETSOL and MICAST

Title: Materials Science Laboratory - Columnar-to-Equiaxed Transition in Solidification Processing and Microstructure Formation in Casting of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions

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Project User Group:
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Honeywell International Technologies Ltd., Ireland
Hydro Aluminium GmbH, Germany
Industeel - Arcelor S.A., France
Snecma - Safran S.A., France
Transvalor S.A., France
Alcan CRV, France
CorusTechnology BV, The Netherlands
Dunaferr Zrt., Hungary
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Sponsoring Agency: National Aeronautics and Space Administration (NASA) and European Space Agency (ESA)

Increment(s) Assigned: 20

Brief Research Summary (PAO): The Materials Science Laboratory - Columnar-to-Equiaxed Transition in Solidification Processing and Microstructure Formation in Casting of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions (MSL-CETSOL and MICAST) are two investigations which supports research into metallurgical solidification, semiconductor crystal growth (Bridgman and zone melting), and measurement of thermo-physical properties of materials. This is a cooperative investigation with the European Space Agency (ESA) and National Aeronautics and Space Administration (NASA) for accommodation and operation aboard the International Space Station (ISS).

Research Summary:

- Materials Science Laboratory - Columnar-to-Equiaxed Transition in Solidification Processing (CETSOL) and Microstructure Formation in Casting of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions (MICAST) are two complementary investigations which will examine different growth patterns and evolution of microstructures during crystallization of metallic alloys in microgravity.

- The aim of these experiments is to deepen the quantitative understanding of the physical principles that govern solidification processes in cast alloys by directional solidification.

Microgravity offers unique opportunity to obtain well controlled solidification conditions for these alloys.

Detailed Research Description: Aluminum alloys are a standard cast metal used in a number of automotive and transportation applications, allowing manufacturers to reduce vehicle weight, increase the strength of components and improve emission controls. One of the most challenging problems associated with aluminum casting is the influence of convection during all stages of solidification. The strength of fluid flow changes the "as cast" internal structure (microstructure) such that the yield, fracture and fatigue strengths of the cast ingot can vary considerably. Although the importance of fluid flow has been recognized for decades, not even a simple model has been developed to predict the effect on microstructure.

Materials Science Laboratory - Columnar-to-Equiaxed Transition in Solidification Processing (CETSOL) and Microstructure Formation in Casting of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions (MICAST) are two investigations which will examine different growth patterns and evolution of microstructures during crystallization of metallic alloys in microgravity.

The major objective CETSOL is to improve and validate the modelling of Columnar-Equiaxed Transition (CET) and of the grain microstructure in solidification processing. This aims to give industry confidence in the reliability of the numerical tools introduced in their integrated numerical models of casting, and their relationship. To achieve this goal, intensive deepening of the quantitative characterization of the basic physical phenomena that, from the microscopic to the macroscopic scales, govern microstructure formation and CET will be pursued. This endeavor will be based on the benchmark data obtained from systematic series of critical experiments under diffusive conditions (critical experiments under convective conditions), with fluid flow in the melt due to natural buoyancy-driven convection (convection controlled by applying an external field, magnetic field or vibration).

CETSOL provides science teams and industrial partners confidence in the reliability of the numerical tools introduced in their integrated numerical models of metallic alloy casting. To achieve this goal, intensive deepening of the quantitative characterisation of the basic physical phenomena that, from the microscopic to the macroscopic scales, govern microstructure formation and CET will be pursued.

Columnar-to-equiaxed transition (CET) occurs during columnar growth when new grains grow ahead of the columnar front in the undercooled liquid. Under certain conditions, these grains can stop the columnar growth and then the solidification microstructure becomes equiaxed. Experiments planned in the framework of the CETSOL experiment are expected to take place in facilities on board the International Space Station (ISS). This is justified by the long-duration required to solidify samples with the objective to study the columnar-to-equiaxed transition. Indeed, the length scale of the grain structure when columnar growth takes place is of the order of the casting scale rather than the microstructure scale. This is due to the fact that, to a first approximation, it is the heat flow that controls the transition rather than the solute flow. Experimental programs are being carried out on ground by the science team and industrial partners on aluminium-nickel and aluminium-silicon alloys.

MICAST studies microstructure formation during casting of technical alloys under diffusive and magnetically controlled convective conditions. The experimental results together with parametric studies using numerical simulations, will be used to optimize industrial casting processes.

MICAST identifies and controls experimentally the fluid-flow patterns that affect microstructure evolution during casting processes, and to develop analytical and advanced numerical models. The microgravity environment of the International Space Station (ISS) is of special importance to this project because only there are all gravity-induced convections eliminated and well-defined conditions for solidification prevail that can be disturbed by artificial fluid flow being under full control of the experimenters. Design solutions that make it possible to improve casting processes and especially aluminum alloys with well-defined properties will be provided.

MICAST studies the influence of pure diffusive and convective conditions on aluminium-silicon (AlSi) and aluminium-silicon-iron (AlSiFe) cast alloys on the microstructure evolution during directional solidification with and without rotating magnetic field.

Project Type: Payload

Images and Captions:

MSL-CETSOL and MICAST Sample Cartridge Assembly, to be processed in the Materials Science Laboratory (MSL) Facility and brought back to Earth for destructive analysis.

Operations Location:

Brief Research Operations:

- The crew will insert a sample cartridge assembly (SCA) into the Materials Science Laboratory (MSL) Low Gradient Furnace (LGF) and power on the MSL.

- Following sample processing the LGF will be cooled to allow removal of the SCA.

- The SCA will be stowed passively until return to Earth on the Space Shuttle.

Operational Requirements: Each sample cartridge assembly (SCA) shall be fully processed in the MSRR MSL LGF furnace, including final solidification step. After return on Earth, the SCA's are destructively analyzed by the investigators. The structure of the solidified metallic alloy is then compared to predictions derived from complex numerical codes. This comparison helps to adapt and improve the numerical codes developed by scientists.

Operational Protocols: The crewmember will insert one SCA into the MSRR MSL LGF. Following power on, the MSRR MSL LGF and vary the power profile of the various furnace heaters to characterize the thermal behavior of the melted metallic alloy in the SCA. Temperature sensors signals will be downlinked to Earth for in-depth assessment by science teams. Numerical codes will provide additional information about the state of the SCA under the thermal constraints on orbit. For each SCA the conditions of the Rotating Magnetic Field (RMF) of the MSL will be varied. Following cool down of the furnace, the SCA is removed from the MSL/LGF furnace and stowed passively until return to Earth. The samples for MSL CETSOL and MICAST are as follows:

- MICAST1 SCA #1:Al-7wt%Si (four solidification velocities, free cooldown;)
- MICAST1 SCA #2: Al-7wt%Si (constant Rotating Magnetic Field (RMF), four solidification velocities, free cooldown)
- MICAST1 SCA #3: Al-7wt%Si-1wt%Fe (four solidification velocities, free cooldown)
- MICAST1 SCA #4: Al-7wt%Si-1wt%Fe (constant RMF, four solidification velocities, free cooldown)
- MICAST1 SCA #5: Al-7wt%Si-1wt%Fe (four RMF settings, four solidification velocities, free cool down)
- MICAST SCA #6: Al-7wt%Si (oriented seed, two solidification velocities, TBD cool down)
- MICAST SCA #7: Al-7wt%Si (oriented seed, two solidification velocities, TBD cool down)
- CETSOL1 SCA #1: Al-3.5wt%Ni-0.5wt%AT5B (three solidification velocities, free cool down)

- CETSOL1 SCA #2: Al-7wt%Si-0.5wt%AT5B (three solidification velocities, free cool down)CETSOL1 SCA #3: Al-7wt%Si (constant solidification velocity, power down)
- CETSOL3 SCA #4: Al-7wt%Si (constant RMF, constant solidification velocity, power down)
- CETSOL1 SCA #5: Al-7wt%Si-0.5wt%AT5B (constant solidification velocity, power down)
- CETSOL3 SCA #6: Al-7wt%Si (constant RMF, three solidification velocities, free cool down)

Review Cycle Status: PI Reviewed

Category: Physical Sciences in Microgravity

Sub-Category: Materials Science

Space Applications: The MSL-CETSOL and MICAST investigations will provide a unique insight into microgravity solidification processes of cast alloys under well controlled conditions.

Earth Applications: These linked experiments aim to improve our understanding of the solidification processes of metallic alloys. As the mechanical properties, and therefore potential Earth-based applications, are directly related to solidification conditions, it is crucial to validate the predictions of numerical models that describe solidification processes. This research has, in fact, a double goal: help industry improve its knowledge of casting processes, so that later on tailored metallic alloys can be created for several applications of our daily life.

Manifest Status: New

Supporting Organization: Exploration Systems Mission Directorate (ESMD)

Previous Missions: MSL-CETSOL and MICAST are a new investigation for microgravity research on-board the ISS. Previous Sounding Rocket experiments on TEXUS and MAXUS.

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