CASE STUDY | MULTI-MATERIAL ADDITIVE MANUFACTURING

Enabling Lighter Multi-Material Rocket Components

Thermo-Calc Solutions used ICME to enable crack-free joining of nickel and titanium alloys, supporting the successful manufacture and hot-fire testing of a functionally graded rocket propulsion component.

~44% lighter
than the original nickel-alloy design

Structural reliability
No cracking observed following multi hot-fire tests

The Challenge

Combining nickel and titanium alloys in rocket propulsion components offers the potential to reduce weight while maintaining performance at high temperatures.

However, directly joining these materials using additive manufacturing can produce brittle intermetallic phases at the interface, making the joint susceptible to cracking.

Overcoming this challenge requires carefully designed intermediate layers that control the local compositions and resulting phase formation. Identifying suitable intermediate compositions through trial and error alone requires extensive time and testing. This was the challenge faced by Skyrora, within the Made-3D project.

The Approach

To address this challenge, Thermo-Calc Solutions applied an Integrated Computational Materials Engineering (ICME) approach to identify the metallurgical mechanisms responsible for cracking and guide the design of intermediate layer compositions (Figure 2).

Computational analysis was used to evaluate candidate compositions and identify a feasible compositional pathway between the nickel and titanium alloys to enable joining (steps 1-2). Experimental observations were analyzed using computational tools to understand the transition-zone microstructures, assess agreement with predictions, and guide subsequent manufacturing iterations (step 3).

By combining modeling and experimental validation in a continuous feedback loop, the team rapidly focused development on the most promising solutions, reducing trial-and-error testing and accelerating optimization (step 4).



Figure 1: Hot-fire testing of 3.5kN LEO engine manufactured by L-PBF. Courtesy of Skyrora Ltd.

The ICME Workflow

Developed by Thermo-Calc

1: INPUT	• Ni and Ti alloy compositions • Candidate intermediate materials
2: PREDICT	• Phase formation • Cracking susceptibility
3: EVALUATE	• Metallurgical compatibility • Experimental evaluation
4: OUTPUT	• Candidate transition layers • Targeted manufacturing trials

Figure 2: The ICME approach Thermo-Calc Solutions developed and used to enable crack-free joining of nickel and titanium alloys.

The Solution

Thermodynamic simulations identified a viable compositional pathway between the nickel and titanium alloys that avoided detrimental phase formation during AM processing. This pathway, shown Figure 3, guided the design of intermediate layer compositions that enabled crack-free joining of the two alloys.

Skyrora Ltd. translated this material solution into a redesigned propulsion component through directed energy deposition manufacturing trials and component production. Additionally, consortium partners in MADE-3D supported powder production, deposition parameter optimization, characterization and testing, connecting the developed materials design with manufacturing and validation.

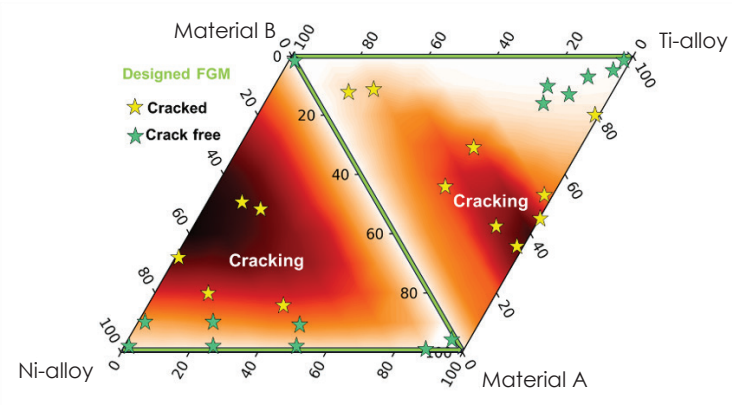


Figure 3: Map showing predicted crack susceptibility (heat map) versus experimental observations (stars) as a function of composition mixtures between Ni and Ti alloys. The green lines exemplify a composition path to avoid the issue.

A Major Milestone for Launch Capacity

By enabling a robust transition between nickel and titanium alloys, this work supported the production of a rocket propulsion component that was ~44% lighter than the original design.

Skyrora Ltd. manufactured the proposed Ni-Ti component and successfully demonstrated their performance through six live firings of a 3.5 kN low Earth orbit engine.

Inspections carried out before and after the hot-fire campaign found no damage to the modified components, validating both their performance under extreme operating conditions as well as the multi-material manufacturing approach used to produce them. This breakthrough creates new possibilities for lighter and more efficient propulsion systems, marking a major milestone for European launch capability and helping bring sovereign access to space one step closer.

Validated component benefits

~44% lighter
than the original nickel-alloy design

Crack-free
After six successful live-firings

Watch a video of the fire-test footage

Software: Thermo-Calc

Database(s): TCNI, TCTI, TCHEA

Solutions Packages: Customized R&D Service

Bring us your multi-material AM challenge!

Talk to an experiment about ICME-based process mapping tailored to your material and application.

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