Robotic Manufacturing of Fibrous Structures in Space

Executive Summary

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Picture:

Motivation:

The study aimed to develop promising robotic fabrication methodologies for a fibre based in-situ robotic fabrication process for application in a lunar habitat as an alternative to existing additive manufacturing methodologies. Previous work has verified fibre composite fabrication processes are capable of a high degree of automation and structural performance.

Methodology:

Based on a survey of precedent fabrication processes, a set of concepts were developed for lunar in-situ fibre-based robotic fabrication processes, including the necessary hardware and robotic systems they would require, and the resulting structures that could be produced. A hyperbolic shell structure was proposed and assessed in terms of its feasibility with respect to lunar conditions, habitat requirements, and automation and structural feasibility. This concept was developed utilizing computational design and physics based simulation tools. A coreless robotic filament winding process utilizing a resin bath infusion system enabled the production of physical prototypes. Mechanical samples with both pseudo-isotropic omnidirectional fibre layouts and unidirectional fibre layouts were produced to validate the mechanical properties and the air permeability of both epoxy and silicone matrix/resin types with basalt fibre.

Results:

- A fabrication methodology, combining coreless filament winding (CFW) with chopped strand fibre (CSF) application, was conceptualized and tested for the production of impermeable fibre composite surfaces. A hyperbolic sample was produced utilizing this process at a scale of 1:1. This sample verifies empirically that the proposed fabrication methodology is capable of producing hyperbolic surface structures that are locally impermeable. This result suggests that, when acting in combination with the high tensile strength of basalt fibre, such structures might be capable of withstanding and maintaining the necessary internal pressure of a lunar structure, assuming any boundary between the surfaces and/or a ground condition was also airtight.

- A multi-stage concept for the robotic fabrication of a bending-active hyperbolic lunar habitat was proposed and conceptually evaluated. Its limitations in terms of level of automation and next development steps were discussed. The components and functionalities of a robotic system that would enable such a process were presented.

- A 1:10 demonstrator of the main structural components of a proposed habitat was robotically fabricated out of basalt fibres and an epoxy resin matrix utilizing a resin bath infusion system. The production of this prototype verified that the syntax of the proposed structure would have performative fibre-to-fibre interaction. It also tested aspects of the multi-stage winding process, in particular, winding 2D curves profiles, bending them into shape, and winding subsequent reinforcement layers.

Publications:

- H. Läkk, Jürgen Schleppi, Cowley, A., Vasey, L. M. Yablonina, M. Menges, A. 2018, “Fibrous Habitat Structure from Lunar Basalt Fibre*,” IAC 2018.* International Astronautical Congress.

Highlights:

Coreless filament winding (CFW) can be combined with chopped strand fibre (CSF) to enable the production of fibre composite structures that are impermeable and rely on minimal formwork during production.

A hyperbolic shell structure is a feasible structure for a lunar habitat and satisfies constraints relating to the process of coreless filament winding, and is also known to be structurally performative. This structure could be created through a multi-step process, where 2D arches are first wound on the ground and bent into position, and subsequently reinforced with additional wound and chopped fibre layers.

A cable driven robotic system could be implemented to enable long span filament winding with minimal scaffolding or supporting formwork. Such a process would be capable of producing structures significantly larger than the size of the robots.

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