

Robotic-controlled, autonomous friction stir welding processes for in-situ fabrication, maintenance, and repair

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NASA's new vision of human and robotic missions to the Moon, Mars, and beyond will demand large and permanent infrastructures on the Moon and other planets, including power plants, communication towers, human and biomass habitats, launch and landing facilities, fabrication and repair workshops, and research facilities so that material utilization and product development can be carried out and subsisted *in-situ*.

The conventional approach of transporting pre-constructed/fabricated structures from earth to the Moon/planets will no longer be feasible due to limited lifting capacity and extremely high transportation costs associated with long duration space travel. To minimize transport of pre-made large structures between earth and the Moon/planets, minimize crew time for the fabrication and assembly of infrastructures on the Moon/planets, and to assure crew safety and maintain quality during the operation, there is a strong need for robotic capabilities for *in-situ* fabrication, maintenance and repair. Clearly, development of innovative autonomous *in-situ* fabrication, maintenance, and repair technologies is crucial to the success of both NASA's unmanned preparation missions and manned exploration missions.

In-space material joining is not new to NASA. Many lessons were learned from NASA's International Space Welding Experiment which employed the Electron Beam Welding process for space welding experiments. Significant safety concerns related to high-energy beams, arcing, spatter, electromagnetic fields, and molten particles were expressed by the astronaut corp. These same concerns also exist with other fusion welding processes, including Tungsten Inert Gas Welding, Metal Inert Gas Welding, Resistance Welding, etc. Furthermore, the fusion welding processes yield many defects such as microcracks, porosity, thermal distortion, shrinkage, etc. They also require considerable consumables (filler rods and gases) during welding, which greatly limit their applications in space.

Wisconsin Center for Space Automation and Robotics (WCSAR) at the University of Wisconsin-Madison has developed unique robotic-assisted, low-mass and low-power Friction Stir Welding (FSW) processes, which requires an insignificant amount of power and mass (in comparison to existing technologies) and offers high dexterity,

flexibility, and versatility. FSW, invented by The Welding Institute (TWI) of U.K. in early 90's, is a solid-state joining process that does not involve melting and resolidification, does not have a moving molten zone, does not generate excessive heat, does not produce hazardous fumes, and most significantly, does not require the consumables. Therefore, it is very attractive to space-based applications.