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INVESTIGATION OF FRICTION STIR WELDING FOR LUNAR APPLICATIONS

Abstract

Recent international efforts for returning to the moon and establishing lunar habitats have driven research of novel aerospace technologies. One such technology is friction stir welding (FSW), often promoted as a capable in-space manufacturing process. FSW has minimal to no process consumables, no requirements for a gaseous environment, and no material melting or slag, making it an attractive alternative to traditional joining techniques. Potential in-space and lunar FSW applications include joining and repairing vehicles and habitats. Previous testing validates FSW techniques for advanced alloys in spacecraft, such as the aluminum-lithium alloys used on the Orion crew module. However, FSW literature has gaps regarding its operation in lunar conditions. Lunar conditions are extreme and present obstacles for FSW, such as a lack of atmosphere and radiative absorption. Studies validate FSW in both a vacuum and non-oxidizing environment; however, cooling through conduction and convection is not possible in the absence of an atmosphere. The lack of conductive and convective cooling and heat influx due to radiative absorption from solar and cosmic sources make thermal management challenging. Poor thermal management can lead to undesirable annealing or precipitation hardening depending on temperatures and the workpiece's material composition. To further understand lunar FSW, this work presents a novel synthesis of existing research and experimental expansion to lunar FSW as a whole. Assuming the workpieces only cool through thermal radiation, in- and post-process temperatures will vary compared to terrestrial FSW. As an approximation, we simulated lunar cooling heat fluxes with in-process and secondary weld heating via a controlled heater. Regulating the heating and cooling of AA6061-T6 allowed an evaluation of material property changes due to the lunar cooling rate. Sample analysis with energy dispersive spectroscopy (EDS) on a scanning electron microscope (SEM) determined the location and size of precipitants, namely magnesium and silicon. Mechanical testing determined the Rockwell hardness and tensile strength of the materials. The associated in-process torque variations due to additional heating suggest energy consumption changes, an important factor with limited in-situ resources. Our testing shows that artificially matching the radiative lunar cooling rates produced samples with material properties different than both the base material and a traditional friction stir weld. We observed that power consumption differed due to the increased in-process temperatures of the weld samples. These quantitative results allow for extrapolation into a qualitative discussion on FSW suitability for lunar applications. This work supports FSW as a valid lunar technology.