On-site Additive Manufacturing by Selective Laser Melting of composite objects

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Introduction: Although the space shuttles have been grounded, man's conquest of space has not ended. Today there are hundreds of government agencies and private companies working on various space programs with many countries announcing plans for missions to the moon and mars. NASA's Curiosity rover which was sent in 2011 is significantly larger than previous rovers thus leading to considerable increase in the launch weight and cost [1]. Similarly, future space missions will require even more equipment thus leading to higher costs. Thus every step must be taken to minimize launch mass. This paper proposes a method for reduction of launch mass of future space programs by on-site manufacturing.

Currently, all the necessary parts of space exploration equipment are manufactured here on earth. Even though, every step is taken to reduce the mass of these parts, mass reduction techniques follow a typical 80/20 Pareto principle behavior; thus, beyond extensive use of carbon fiber and other light weight materials, it is very difficult to further reduce mass. The next logical step in order to reduce launch costs and increase man's presence in space is on-site production and manufacturing. Undoubtedly, in-situ production on another planet only makes sense if local on-site materials are used. The adopted manufacturing process must be completely automated, highly reliable, and very robust. It must be able to create complex geometry from various granular and powder materials using additive manufacturing methods.

SLM process: Selective Laser Melting (SLM) is a powder based technology in which the object is built layer by layer using a laser beam to melt the powder on a vertically moving platform [2].

SLM is an appropriate method for in-situ production on Mars as it is able to create high quality 3D parts from various granular materials. In contrast to other additive manufacturing methods which use engineered materials, SLM allows for the production of accurate [1]and complex metallic and ceramic objects. Unlike Selective Laser Sintering (SLS), the material is fully melted which results in objects with better mechanical properties. Additionally, the process is more robust in regards to changes in raw material [1] [3]. SLM enables building parts with minimal support structures since the powder bed supports the part as it is being built. Up to now, majority of the research on SLM have focused on improving the quality of metallic parts [4].

In-Situ material: In order to produce parts on Mars, naturally, raw material in Martian soil must be used as much as possible. Latest investigations have shown Martian surface to be covered by regolith comprised mostly of Silicon, Iron, Aluminum, and Magnesium compounds [5] [6].

Silica powder, the main constituent in typical sand, is one of the most abundant materials on earth, moon, and even on Mars according to NASA's spirit rover analysis [5] [6]. However, conventional glass and ceramic making techniques are inadequate for creating complex and dimensionally accurate geometries on Mars. Manufacturing with Silica using the SLM process facilitates fully automated production of highly accurate glass and ceramic parts.

Recently, a research project has been launched at FH Aachen University in Germany in order to devise a SLM process for creating ceramic and glass parts from Silica powder and sand. The study is a continuation of previous research on SLM using Silver, Cobalt Chromium and Stainless Steel. A number of sample parts created from beach sand with a 100 W fiber laser SLM machine are shown in figure 1. The parts confirmed previous simulation results that by using the proprietary parameter set, it is possible to create dense solid structures with acceptable mechanical properties.

Figure 1: Sample parts created by SLM from sand

Preliminary investigations have shown promising results producing rigid glass objects from sand using the proprietary technique. In figure 2 a microscopic image from a transparent glass part is shown.

In this process, unlike the MIT 3DP glass printing technology [7], a binder material is not used and the Silica powder is selectively melted by the laser. Thus it is possible to produce transparent optical glass and lenses with high surface quality.

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Figure 2: Transparent glass created with SLM

Another material which is thought to readily exist in Martian soil is iron [5] [6]. Similarly to Silica, iron is a suitable and proven raw material for manufacturing using the SLM process. The production of high quality steel parts with SLM has been successfully demonstrated at various institutes around the world [4].

SLM advantages: In comparison to other automated additive manufacturing techniques, SLM provides many advantages for in-situ manufacturing in outer space. Using the SLM process, it is possible to fuse granular materials and create 3D objects from a wide range of raw material. The objects can be created from a single raw material purely based on local availability or alternatively, a multi-material product can be constructed using SLM. For example, to produce a complete enclosure, Martial soil can be sintered to form ceramic "brick" material reinforced with fused iron rods while the Silica powder can be used to produce transparent glass. Unlike other techniques such as Contour Crafting [8], SLM process does not require any raw material from Earth and does not need water or binding material. Granular and powder elements from Martian soil can be mixed to produce composite parts or used separately to produce a heterogeneous product.

Another major advantage of the SLM process is that it is highly scalable. The size of the produced objects depends on the size of the platform and elevator while production rate depends on the laser output power and scanning strategy. Currently, at FH Aachen it is possible to successfully fuse various materials such as silver, chrome, and various steels using a 100 Watt fiber laser [9] [10]. On Mars, it may be possible to start experiments with the SLM process with the laser system currently onboard the Curiosity Rover. Once the process has been proven to work, a small SLM machine with a medium output power laser system can be sent. As requirements grow multiple laser systems can work in parallel in order to speed up the process. Since the process is highly distributable, it is possible to send multiple small and low weight laser systems instead of launching costly and heavy high powered laser systems. The size of the platform will need to increase depending on the maximum desired object size. It is also possible to create the parts for a larger SLM machine on-site using the smaller machine.

Summary: SLM process as an automated additive manufacturing technology has been proven to be suitable for producing complex and accurate geometries from various metals. Recent investigations at FH Aachen University have shown that ceramic and glass structures can be made from common beach sand using a proprietary process. On Mars, SLM process can enable the creation of in-situ manufacturing of products from various on-site materials without the need for any raw material from Earth. The process may also be used to manufacture a complete base for future astronauts at considerable cost savings.

References:

[1] NASA press kit (2011), *Mars Science Laboratory launch*. http://www.jpl.nasa.gov/news/press_kits

[2] Gebhardt, A. (2011), *Understanding Additive Manufacturing,* Hanser publications

[3] Kruth J.P., Wang Z., et al. (2003), *Lasers and materials in selective laser sintering,* Assembly Automation, Vol. 23 Num. 4, pp. 357-371

[4] Yadroitsev, I. Pavlov, M. et al. (2009), *Mechanical properties of samples fabricated by selective laser melting,* Assises Européennes du Prototypage & Fabrica-tion Rapide, June 2009, pp. 24-25

[5] McSween, H.Y. et al. (2004) *Basaltic Rocks Analyzed by the Spirit Rover in Gusev Crater,* Science 305, 842, DOI: 10.1126/science.3050842

[6] Carr, M.H., (2007), *The Surface of Mars,* Cambridge University press

[7] Grau, J. (1998), *Fabrication of Engineerd Ceramic Components by the Slurry-Based Three Dimensional Printing process,* Ph.D. Dissertation, Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA

[8] Dr. Khoshnevis, B. (2005), *Lunar Contour Crafting A Novel Technique for ISRU-based Habitat development,* American Institute of Aeronautics and Astronautics Conference, Jan. 2005

[9] Gebhardt, A., Fateri, M. (2012), *Numerical Investigation of Selective Laser Melting of Silver,* Fraunhofer Direct Digital Manufacturing Conference

[10] Gebhardt, A. et al. (2010), *Additive Manufacturing by Selective Laser Melting: The realize desktop machine and its application for the dental industry,* 6^{th} International Conference on Laser Assisted Net Shape Engineering, LANE 2010