Sam Johnson

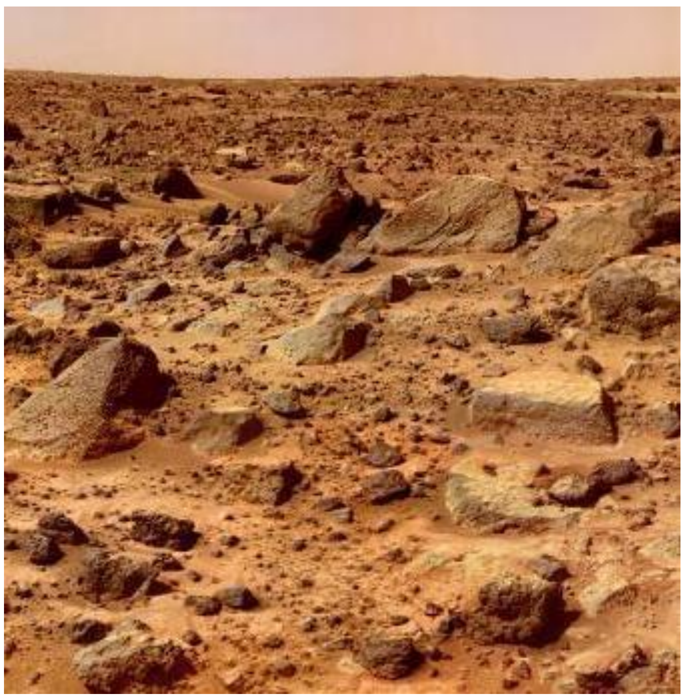
Design Paper

Dr. Haas

5/11/2020

Proposal Format:

Figure 1: The Rocky Terrain of Mars



The terrain of Mars is rocky, consisting of many different types of minerals and soil compositions. Martian mudstone, sandstone, shale and basalt (among others) are invaluable to study in order to better understand Earth's neighboring planet.[1]

This proposal centers on the potential use of Tungsten Carbide as a primary material for cutting tools for quarrying (hydraulic drills, saws, etc.). Another use as a coating to improve the life of existing materials exposed to the harsh environment of Mars. The recent discovery of a large Tungsten deposit near Earth's Mars colonization site allows for Tungsten Carbide to be feasibly implemented into creating new tools or protecting existing tools. Quarrying applications like these will allow for easy sampling of minerals on mars in addition to creating a construction base for colonial infrastructure.

Properties and Testing:

Tungsten Carbide is a composite material made of tungsten carbides in a metal matrix of cobalt.[2] Tungsten Carbide is usually made of equal parts Tungsten and Carbon atoms appearing as WC, or as a difference phase W_2C.[2] Tungsten Carbide also has a few variations depending on changes in molecular structure. In most cases, Tungsten Carbide is harder than most steels, has great mechanical strength, transfers heat quickly, and resists wear and abrasion better than other metals.[3] These wear-resistant properties make Tungsten Carbide a great option for applications involving the manipulation of corrosive and/or hard materials.

Density has been measured to be 15,630 kg/m[4] and Young's Modulus has been measured to be 668 GPa. Looking at tensile strength, Tungsten Carbide can withstand 344 Mpa, while compressive strength is much greater at 2683-2958 MPa. These values are found through tensile and compression testing. A high mechanical strength is also characterized by a melting point of 2777°C. Tungsten Carbide has a high melting point and relatively low level of thermal conductivity—at @100°C, thermal conductivity is 86 W/mK. This makes Tungsten Carbide more of an insulator than a conductor. The Vickers Hardness test presses a pyramid-shaped indenter onto a test surface. The measured impression determines the hardness. The hardness of Tungsten Carbide is about 2500 HV, which is much lower compared to Diamond's 10,000 HV on the Vicker's Hardness scale, but still higher than materials like Quarts at 1200 HV. Tungsten carbide is not magnetic due to the non-magnetic properties of W and C. Tungsten Carbide also has a low electrical resistivity and works well as an electrical insulator. The appearance of Tungsten Carbide is that of a dull and grey powder. To be able to work, it must be mixed with a binding material (e.g. Nickel). Once mixed into a multi-metal compound, it can be further finished to have anything from a matte to polished surface. Tungsten Carbide oxidizes at 500-600 °C. It is resistant to most substances, only being affected by nitric acid, plus fluorine and chlorine gas.[2] The tough properties of Tungsten Carbide are greatly influential it's applications on mars.

The average temperature of Mars ranges from -87 to -5 degrees Celsius. The thin atmosphere is comprised of 95.3% Carbon Dioxide, 2.6% Nitrogen, and 1.9% Argon. There are trace measures of Oxygen, Carbon monoxide and Water Vapor.[2] Tungsten Carbide is not reactive with any elements within the atmosphere of Mars. A resistance to deformation and molecular stability within Mars' atmosphere makes it a good option for cutting tool purposes.

The raw material found at the Mars Base is natural tungsten ore. Activated Carbon is not in abundance in this location and will have to be brought from earth. An alternative to bringing Activated Carbon is to make it on Mars from waste from man-made materials.

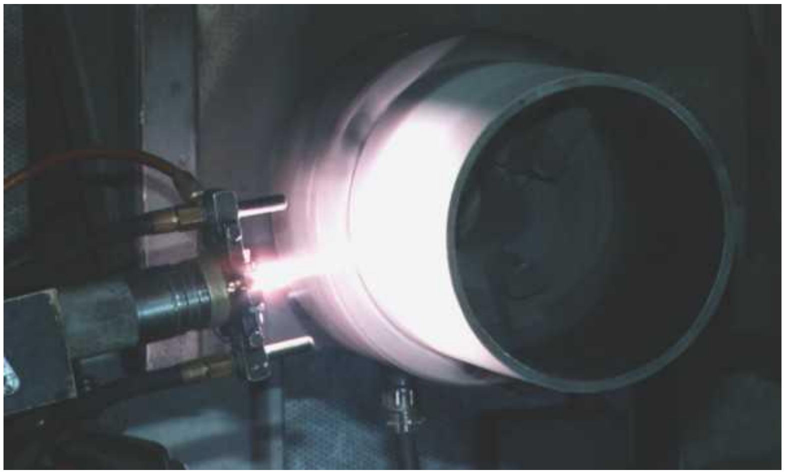
Applications and Performance:

Tungsten Carbide works well on earth as smaller cutting tools for high-precision machining. The abundance of material on Mars would allow for larger cutting tools to be manufactured efficiently and effectively. Large-scale rock saws and drills would allow for efficient trenching, quarrying and excavating. Virtually any surface on mars could be leveled to build man-made structures.

Figure 2: Excavator with Rock Saw Blade Attachment

In addition to being the primary makeup of a cutting tool, Tungsten Carbide coatings could be applied to improve the life of weaker cutting tool materials that are more easily dulled from use. Such applications would be achieved through Plasma Spray Coating. From a processing standpoint, less steps are needed to apply a protective cutting versus creating a brand-new tool. Processing advantages and disadvantages will be provided in the following section.

Figure 3: Plasma Spray Coating Metal



Processing:

Tungsten Carbide is created by Powder Metallurgy. Powder Metallurgy doesn't produce much (if any) waste material, especially with Tungsten Carbide. The initial material of Tungsten Carbide synthesis is WO_3 (also known as tungsten acid or ammonium tungstate). The carbonization of tungsten by carbon happens in a graphite furnace with hydrogen atmosphere.[4] Tungsten carbide powder acquired after this process is indefinitely melted, at a size of 3-5 μm.[3] Starting with nano-phased powders of metal tungsten, reduction and carbonization processes will result in nano-phased tungsten carbide with a size of ~30nm. [3] The process of Tungsten Carbide fabrication is more specifically known as calcination-reduction-carburization. [3] At a 'low' temperature of ~800°C, ultrafine tungsten carbide powders can be commercially manufactured with a grain size below 0.5 μm.[3] Synthesis at higher temperatures of up to 4000°C is more ecologically efficient than 'low' temperature synthesis.3 The tungsten carbide powder can be further mixed with 'binding materials' to hold shapes, allowing for pressing of parts or sheet rolling.[3]

Reaching high temperatures to process Tungsten Carbide will be extremely inefficient on Mars. A large fuel source will be needed to purify the Tungsten ore into Tungsten Oxide before churning it down into (small, grain sized) powder and combining it with Carbon via the aforementioned process.

Processing the finished Tungsten carbide into cutting large scale tools is another story. Tungsten Carbide powder will have to be compressed and heated within molds at over 1000 degrees Celsius. After heating, they must be honed to proper dimensions. This includes the overall shape of the tool and the cutting edge radius. Honing is done by a mill or lathe with diamond-coated bits. Large scale cutting tools such as the rock saw or other drills will need to be Plasma sprayed. This process entails using a heat source to fuse Tungsten Carbide powder to the cutting tool surface.

Dedicated buildings with extensive insulation will be an added cost to the processing of Tungsten Carbide on Mars.

Sustainability:

Because it's a compound, there is no loss of durability when Tungsten Carbide is recycled. This is an important factor to take into consideration. Assuming that proper fuel and carbon sources can be allocated, dull cutting tools can be melted and molded into new, sharp ones or spray applications can be reapplied.

Immense amounts of fuel will have to be burned to create an environment hot enough to re-melt and recycle Tungsten Carbide. Depending on what this fuel is, potentially harmful waste products could be released into the atmosphere. Humans can't breathe Martian air anyway—Mars colonists will have no breathing issues with proper respirators.

Competing Technologies:

The main competing excavating technologies are Diamond Cutting Tools as well as ANFO explosives.

Diamond cutting tools improve upon Tungsten Carbide due to their higher hardness. Diamond’s Vicker hardness rating is 10000 HV, whereas Tungsten Carbide is 2500 HV. Diamond can withstand higher compressive forces without fracturing or chipping. The downside of diamond is the expense. It’s expensive to bond diamond (via sintering) to a cutting surface using glass and ceramic powder.

In terms of quarrying, ANFO (Ammonium Nitrate) explosives are most commonly used to clear rock and sediment out of designated sections. This is a cheap and effective method to move rock at the cost of accuracy and need to clean up rubble. For very specific excavating practices, Tungsten Carbide Cutting tools would work at a higher degree of accuracy.

References:

1)

Wild, Flint. “What is Mars?”. National Aeronautics and Space Administration. 2015.

2)

Franz, Heather B.; Trainer, Melissa G.; Malespin, Charles A.; Mahaffy, Paul R.; Atreya, Sushil K.; Becker, Richard H.; Benna, Mehdi; Conrad, Pamela G.; Eigenbrode, Jennifer L. "Initial SAM calibration gas experiments on Mars: Quadrupole mass spectrometer results and implications". Planetary and Space Science. 2017. Vol 138, p. 44–54.

3)

Alexey S. Kurlov, Aleksandr I. Gusev. Tungsten Carbides Structure, Properties and Application in Hardmetals. Russia: Springer International Publishing. 2013. p. 5-46.

4)

Cardarelli, François. Materials Handbook: A Concise Desktop Reference. Second Edition. Tuscon Arizona: Springer Science & Business Media. 2008. Chapter 10.5.6 Tungsten Carbide p. 639-643.

Figure References:

1)

Mars Surface. Coffey. [accessed 2020 May 10]. https://www.universetoday.com/14885/mars-surface/

2) Carbide Saws. [accessed 2020 May 10]. https://www.echidna-rocksaws.com/products/CarbideSaws/

3)

Plasma Spray Coating. Massachusettes institute of Technology. [accessed 2020 May 10]. http://fab.cba.mit.edu/classes/961.04/projects/RegXuProj/MasProjII.htm