

3D Printing of Wear-Resistant Materials: A Review and Perspectives in Oil Sands Applications

Young Li
Suncor Energy Inc.
Calgary, Alberta, Canada

Stefano Chiovelli
Suncor Energy (Syncrude) Operating Inc.
Calgary, Alberta, Canada

Darius Remesat
Suncor Energy Inc.
Calgary, Alberta, Canada

Billy Rideout
Exergy Solutions Inc.
Calgary, Alberta, Canada

Marcus Ivey
Exergy Solutions Inc.
Calgary, Alberta, Canada

Duane Serate
Suncor Energy Inc.
Calgary, Alberta, Canada

Simon Yuen
Suncor Energy Inc.
Calgary, Alberta, Canada

Brian Doucette
Suncor Energy Inc.
Calgary, Alberta, Canada

Dave Waldbillig
Exergy Solutions Inc.
Calgary, Alberta, Canada

ABSTRACT

Additive manufacturing (AM) has received attention from the oil sands industry in recent years. Oil sands producers use AM technologies to fabricate parts with complex geometries that are difficult or impossible to make via conventional manufacturing. AM can also enable rapid iteration of design ideas and printing of prototypes directly from 3D CAD models quickly and cost-effectively. 3D printed cemented carbide and other wear-resistant materials have been investigated to improve operational reliability and reduce production costs. As AM is still in the early development stages, oil sands producers need to understand the capabilities and limitations of the various 3D printing processes available, comprehensively identify and validate suitable applications for their use. This paper reviews the current 3D printing technologies for making cemented carbide wear-resistant materials and emphasizes the potential applications, restrictions, and challenges of 3D printing applications in the oil sands industry.

Keywords: Additive manufacturing, 3D printing, Cemented Carbide, oil sands

INTRODUCTION

Canada's oil sands are the third largest deposit of crude oil in the world, and consist of a mixture of sand, water, and bitumen. Due to an aggressive operating environment that includes abrasive sands and

corrosive chemicals, oil sands equipment and process piping often experience severe wear and erosion-corrosion, which can lead to the risk of equipment failures, plant downtime or, even worse, environmental leaks [1]. For more than half a century, oil sands producers have collaborated with materials suppliers, equipment fabricators, and technology providers to develop wear technologies to reduce downtime and improve operational reliability. The National Research Council Canada (NRC) Mining Materials Wear and Corrosion consortium [2] and the Innotech Alberta Materials and Reliability in Oil Sands (MARIOS) program [3] are two leading consortiums connecting oil sands producers with manufacturers to collaboratively solve wear, erosion, and erosion-corrosion problems. Current research activities include materials for slurry transport applications, wear-resistant overlays, non-metallic liners, sintered metal carbides, composite chrome white iron, and additive manufacturing (AM).

Additive manufacturing, also known as 3D printing, is a manufacturing method in which an object is built up layer by layer based on a 3D CAD model. Both terms are used interchangeably in this paper. One of the key advantages of 3D printing is the ability to fabricate complex geometries that would be difficult or impossible to construct by conventional manufacturing methods. The leading industrial sectors for 3D printing applications are automotive (16.4%), followed by electronics (15.4%), aerospace (14.7%), medical/dental (13.9%), academic (12.3%), power/energy (11.6%), and other industries [4]. In recent years, oil sands producers have worked together with technology developers to apply 3D printing technologies for oil sands operations. Syncrude is partnering with Innotech Alberta and the University of Alberta on wire arc additive manufacturing (WAAM) and plasma transferred arc additive manufacturing (PTA-AM) technologies to construct components for ground engagement tools (GET). Suncor Energy has initiated an advanced materials and manufacturing (AMM) program to explore binder jetting 3D printing (BJ3DP) and powder bed fusion (PBF) technologies for building tailings solvent recovery unit (TSRU) nozzles, rotary wet screen spray nozzles, autosamplers, and other wear parts. The AMM program collaborates with industrial partners, Exergy Solutions and Precision ADM, and is partially funded by Next Generation Manufacturing Canada (NGen), Canada's advanced manufacturing supercluster.

Additive manufacturing enables the fabrication of complex geometries and rapid prototyping directly from 3D CAD models. At present, oil sands producers and technology developers are focused on investigating AM manufacturing processes, evaluating AM material properties, and identifying suitable applications for 3D printing. However, AM development in the oil sands industry is still in its infancy. There exist many different 3D printing technologies; thus the processes to make a 3D printed part are variable. Even for the same material, different printing technologies can yield vastly different material properties. AM technologies are not simply a direct replacement for conventional manufacturing methods such as machining or casting. AM parts often need to be redesigned for the 3D printing process, and the geometric stability and microstructural characteristics have to be analyzed. The defects of 3D printed parts are usually difficult to be detected by non-destructive examination (NDE). Oil sands producers need to understand the capabilities and limitations of the various 3D printing methods and comprehensively identify and validate suitable applications. This paper reviews the currently available 3D printing technologies for printing wear-resistant materials, with an emphasis on the potential applications, restrictions and challenges of 3D printing for the oil sands industry.

3D PRINTING - AN OVERVIEW

ISO/ASTM 52900 defines additive manufacturing as the process of joining materials to make parts layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies [5]. The commercial use of additive manufacturing emerged in 1987 with materials of resin, polymer or plastic. AeroMet in the UK developed the Laser Additive Manufacturing (LAM) process to manufacture titanium alloy parts for the aerospace industry in 1997 [4]. In recent years, metal printing has spurred significant interests and investment. Three primary business drivers for 3D printing technologies are time saving, performance improvement, and cost reduction.

Time Saving Conventional machining methods require customized tools built for each new part. 3D printing can eliminate tooling and directly convert a 3D model to the final products. With additive manufacturing technology, manufacturers can make the prototypes in hours or days and rapidly iterate through design ideas in development projects.

Performance Improvement 3D printing can combine multiple materials in a single part to achieve optimized properties, such as mechanical strength, toughness, or corrosion resistance. AM technologies can also consolidate numerous parts together and improve performance. For example, Precision ADM has manufactured industrial gas turbine vanes by direct metal laser sintering (DMLS) system (Fig. 1). In this case, additive manufacturing enabled three parts to be combined into a single piece, resulting in improved spare parts supply and operational reliability.

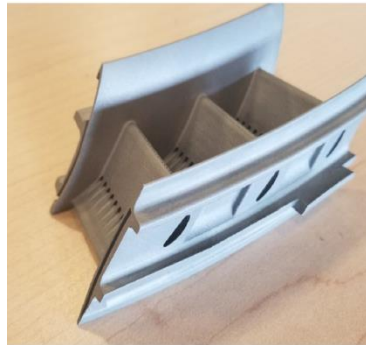


Figure 1: Industrial gas turbine parts consolidation by Precision ADM

Cost Reduction 3D printing can save money on molds and tooling, especially for parts produced in lower volume. AM technologies have also proven to effectively reduce costs by printing near-net-shape parts that require only finish machining. It is a substantial cost saving for expensive metals like titanium or tungsten carbide, which are difficult to cut, weld or cast.

There are over a dozen distinct additive manufacturing technologies. Powder Bed Fusion (PBF), Binder Jetting 3D Printing (BJ3DP) and Direct Energy Deposition (DED) are three main processes for the 3D printing of cemented carbide and other wear-resistant materials. A comparison of these 3D printing processes is summarized in Table 1.

Powder Bed Fusion PBF is the first and the most widespread process for metal additive manufacturing (Fig. 2). PBF is defined in ISO/ASTM 52900 as “Powdered material is selectively consolidated by melting it together using a heat source such as a laser or electron beam” [5]. As mentioned in the definition, two possible heat sources, laser and electron beam, can be used to melt the metal powder and build the part layers upon layers. These methods are also referred to as selective laser melting (SLM) and electron beam melting (EBM).

PBF can print a wide range of metals including tool steel, stainless steel, alloys of titanium, aluminum, nickel, cobalt, copper, and cemented carbides. PBF systems are relatively expensive and the operation costs are high due to the long lead time of the printing process. PBF can typically print up to part sizes on the order of 250 mm. The process is primarily used for small parts with complex geometries that require higher resolution, or the parts which would be difficult to manufacture via conventional machining methods. The relatively low printing rate and high machine costs associated with PBF mean that the process is best suited for small, low-volume, high-value parts most common in aerospace and medical industries.

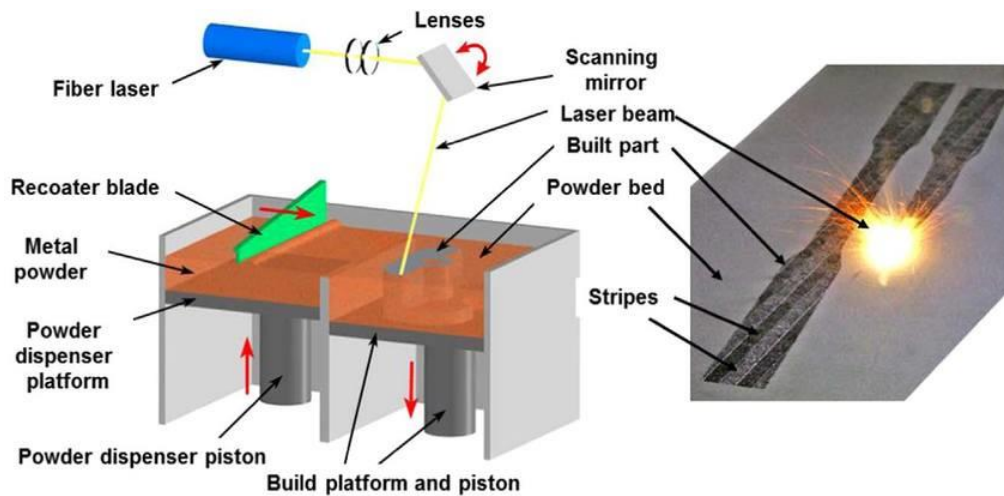


Figure 2: Powder Bed Fusion 3D printing system from EOS GmbH [4]

Binder Jetting BJT was initially developed by the Massachusetts Institute of Technology (MIT) and is defined in ISO/ASTM 52900 as “An additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials” [5]. After printing, post-processing steps including de-binding and sintering are carried out on the printed parts to fully consolidate the parts and obtain the required strength and properties. Post-processing usually plays a more critical role on the materials properties and quality than the printing process itself.

The BJT process is most suitable for small, thin, and high-resolution parts. Larger parts are still possible with the BJT process, but volumetric shrinkage during the sintering step must be compensated for, making this process challenging and less attractive to build larger parts.

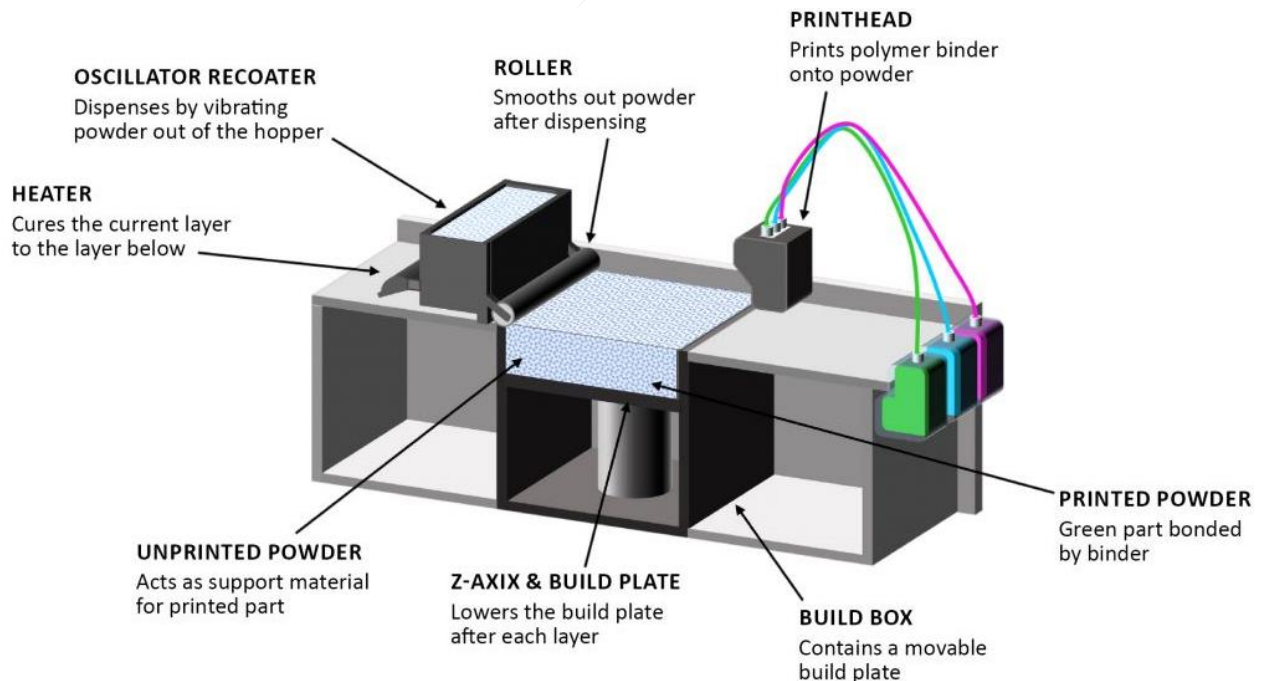


Figure 3: Binder Jetting 3D printing process and system [6]

Directed Energy Deposition

DED utilizes thermal energy to directly fuse materials together (Fig.