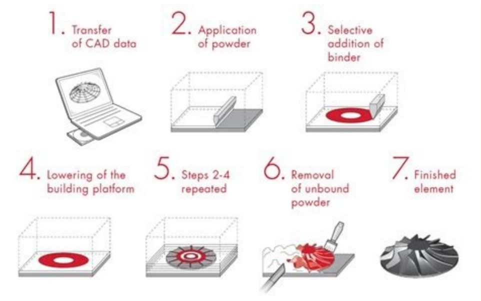
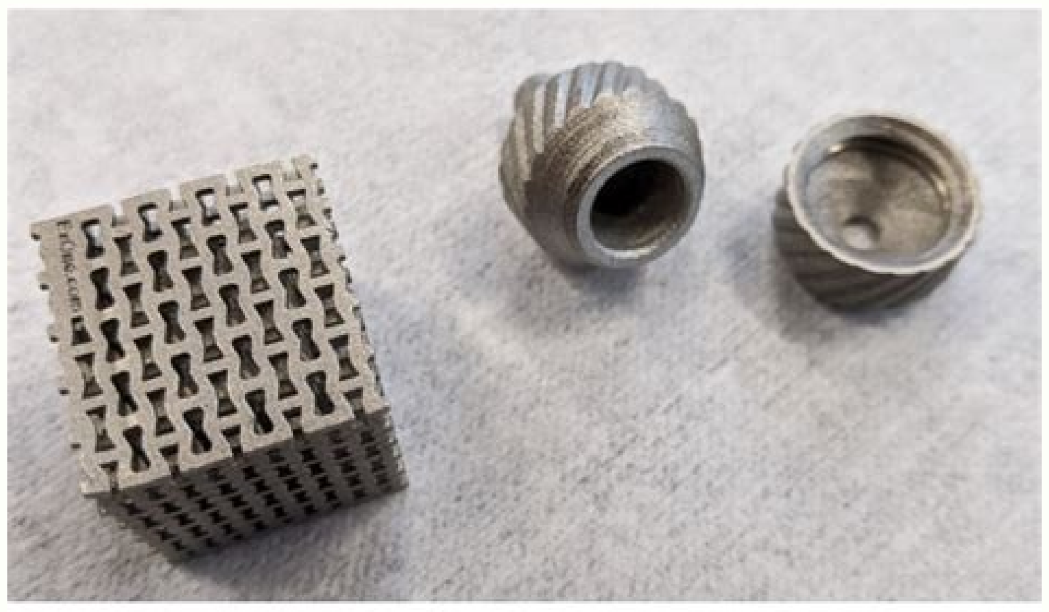
Binder jetting pdf





Metal components produced using binder jetting additive manufacturing

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Binder Jetting 3D Printing of Titanium Aluminides Based Materials: A Feasibility Study

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This study offers the ability to fabricate nearly dense titanium aluminides-based structures using a hybrid method that encompasses binder jetting 3D printing (3DP) of Ti–6Al–4V followed by pressureless ex situ infiltration with Al. Microstructure characterization and phase analysis are performed by scanning electron microscopy equipped with energy dispersive spectroscopy and X-ray diffraction, respectively. The microstructure of the samples fabricated by means of pressureless ex situ infiltration at different temperatures and with various durations is studied and discussed. The nearly dense titanium aluminides-based composites shows a Young's modulus of ≈145 GPa, a compressive strength of ≈1.4 GPa and a bending strength of ≈483 MPa. To demonstrate technological capability of this hybrid approach, complex near-net-shaped objects are fabricated.

1. Introduction

Due to the superior properties over conventional Ti alloys, titanium aluminides have potential applications in the fields of aerospace and automotive industries.[1,2] Titanium aluminides (Ti_xAl_y) have low density (3.9 g cm^{-3}), good resistance to oxidation, and high strength at elevated temperature. Therefore, the applications of titanium aluminides are not only limited to the aerospace and automotive industries but also recently, porous Ti_xAl_y is used as gas and liquid filters at elevated temperatures.[3]

Higher production costs hinders the use of conventional processing routes such as casting, powder metallurgy, investment casting, and ignot forging for fabriction of Ti_xAl_y.[2] Also, the brittleness of the Ti_xAl_y makes them difficult to machine materials. Therefore, the need for near-net-shape processing route is vital.[3] Morsi et al.,[4,5] and Fu et al.[6] reported the hot extrusion route for the fabrication of Ti_xAl_y. This process has been proven as a suitable method for the fabrication of near-net-shaped Ti_xAl_y—materials with limited porosity. Elemental powder processing route has been studied over the years for the fabrication of intermetallic compounds. In this route, a powder blend comprised of elemental powders (Ti and Al) is prepared, consolidated and post-processed through reactive sintering synthesis. During reactive synthesis, Ti_xAl_y is fabricated via diffusion of Al atoms in Ti. But due to Al diffusion, a Kirkendall porosity forms, which leads to bloating of product formed.[6]

During liquid-state reactive sintering of solid Ti and liquid Al, it was observed that it gave rise to two exothermic peaks at 520–570 and 660 °C, respectively.[7,8]

The second exothermic peak is caused by the expansion of the sample. The resulting sample was so fragile that it could not be used for further mechanical testing.

The intermetallic compound, which forms at a temperature above the melting point of Al, is $TiAl_3$ due to the exothermic reaction between solid Ti and liquid Al.[9] The intermetallic compound $TiAl_3$ shows minimum free energy of formation among the intermetallic compounds such as TiAl, Ti_3Al, and $TiAl_3$ in the temperature range of 273–1473 K.[10]

The additive manufacturing provides an advantageous edge over conventional techniques due to its capability to fabricate complex structures from computer-aided design (CAD) file. Recently, a lot of work has been done on fabricating of complex Ti_xAl_y-based parts using selective laser melting (SLM) and electron beam melting (EBM).[11,12] However, many problems can occur in these processes, such as solid-state cracks, residual thermal stresses due to repeated rapid melting and solidification nature of the fabrication.[11–13] In constrast, binder jetting 3D printing (3DP) does not meet these challenges because it works at low temperatures. The binder jetting 3DP works on the principle of the layer-by-layer printing, in which the binder ink is distributed on the powder layer. The green parts are then further heat-treated and post-processed.[13,14] The detailed review on binder jetting 3DP can be found in ref. [15]. Not much work has been reported on binder jetting 3DP of Ti_xAl_y-based materials. Thus, in the present work an additional approach to the above-mentioned SLM and EBM methods was investigated. We propose a feasible processing route for Ti_xAl_y-based parts using additive manufacturing technique and reactive melt infiltration. It is well known that pressure-assisted or pressureless reactive and nonreactive infiltration of porous preforms by a

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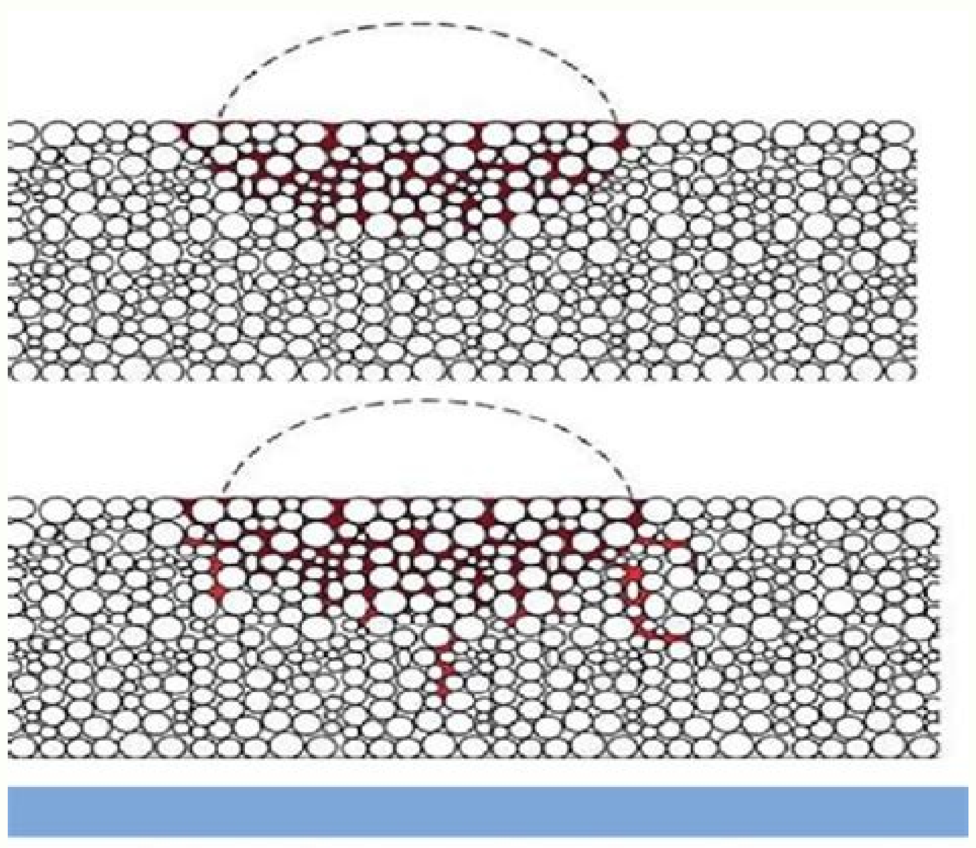

: presentation of a binder droplet pattern inside a powder be
roplet after reaching equilibrium state); (a) assuming small po
ssuming large pore size [3].

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Binder jetting is defined as "an additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials."From: Power Ultrasonics, 2015 As the first additive manufacturing systems to unlock benefits like mass production of end-use parts, mass customization, tooling-free manufacturing and more, the Shop System and Production System are poised to kick-start a revolution in manufacturing, what Desktop Metal calls Additive Manufacturing 2.0. And at the heart of both systems is binder jetting, a technology that enables additive manufacturing to compete with traditional mass production methods by delivering a host of benefits - chief among them speed. Because they're built around inkjet print heads - the same type of print heads found in millions of at-home printers - binder jetting printers can produce parts as much as 100 times faster than laser powder bed fusion systems. While that speed allows binder jetting systems to deliver per-part costs that can compete with traditional processes like casting and forging, speed is just one of many advantages. Binder jetting also offers many of the traditional 3D printing benefits - everything from the ability to create complex geometry, including internal features and channels, to unlocking generative design to assembly consolidation and more. It's the combination of those benefits with the speed of binder jetting that truly unlocks the potential of Additive Manufacturing 2.0. Besides being fast and capable of manufacturing complex shapes, binder jetting systems are also incredibly accurate. With a native resolution of 1200 dpi, the Shop System is the highest resolution single-pass binder jetting system available, and is capable of producing as many as 670 million drops of binder each second. That precision makes it easy to create parts - like this clipper blade - that feature incredibly fine details that would normally require expensive tooling. The Production System, meanwhile, combines 1200 dpi resolution and layer heights as small as 50 µm with a unique Single Pass Jetting system that uses every movement of the print head to build parts. The result is a system that is not only accurate enough to print a watch bezel with precise detailing around its edge, but also fast enough to produce as many as 1,200 of them in a single build, at a cost of just $1.06. Like other 3D printing approaches, binder jetting's tooling-free nature makes it easy to customize designs. Unlike other approaches, though, binder jetting also enables batch production, meaning manufacturers can produce multiple versions of a single part in a single print, ultimately helping to reduce part costs. One of the other key areas where binder jetting systems excel has to do with what happens after parts are printed. For many laser-based systems, the first step following printing is often hours of post-processing to machine away support structures and free parts that must be welded to the printer's build plate. Binder jet parts, by comparison, are supported by loose powder in the build chamber, eliminating need for time-consuming post processing. The lack of support structure also allows parts to be densely nested, maximizing the number of parts produced per build and helping to ultimately lower per-part costs. Further reducing part costs is the fact that some binder jetting systems - particularly the Production System - use low-cost MIM powders, meaning customers can rely on established suppliers to deliver the volume and variety of metal powder needed to support volume production. Laser-based systems, by comparison, have a limited materials menu. Because they only work with low-oxygen metal powders, their material costs can reach as high as $60 per kilogram, resulting in finished part costs that run into the hundreds of dollars per kilogram - far too costly for mass production. Binder jet systems can recover and reuse loose powder - the Production System can be recycled as much as 99 percent of unused powder - resulting in less waste and more cost efficiencies. With Desktop Metal-engineered powders and processing parameters, the Shop System is designed to be a turnkey binder jetting solution, allowing users to easily go from design to finished part. Among the most important characteristics of those parts is the fact that binder jet parts are isotropic, or equally strong in all directions. That hasn't always been true for 3D printed parts. Because they're built up layer-by-layer, some parts - depending on printing method - may be stronger in one direction than another. To compensate for the difference, designers were forced to reorient parts for printing to ensure mechanical stresses fell along their strongest axis. Binder jet parts, by comparison, emerge from the furnace fully dense, meaning they're equally strong in all directions, giving designers and engineers greater freedom to both design and print parts in the way that best suits their needs. Binder jetting also changes the cost equation wWhen compared to traditional manufacturing, which have largely been dominated by labor and material costs. Binder jetting, by comparison, uses less expensive materials, but has higher equipment costs, placing more emphasis on equipment and labor costs associated with depowdering. Because they're faster and more productive, binder jet systems can help drive down those equipment costs by allowing manufacturers to more quickly amortize the cost of equipment over larger production volumes. On the labor side, costs will be driven down as automation continues to develop. By investing in binder jet systems, manufacturers can ultimately expect to see a variety of savings - the initial savings from lower material cost and production efficiency and speed, and later savings from reduction in labor cost. Binder jetting's impact, however, seems likely to reach beyond the manufacturing floor. A key technology driving the emergence of Additive Manufacturing 2.0, today is poised at the edge of a revolution, one that will reshape how we manufacture many of the things we use everyday. Editor's Note: Visit What Is Additive Manufacturing for more AM 101 information. Binder jetting is a 3D printing process that uses a liquid binding agent (think: glue) deposited onto a build platform to bond layers of powder material and form a part. Binder jetting can be used to print a variety of materials including metals, sands and ceramics. Markets for this process include industrial applications, dental and medical devices, aerospace components, part casting, luxury applications, and more. Binder jetting 3D printing systems include machines from Desktop Metal, Digital Metal, ExOne, GE Additive, HP (known as Metal Jet Fusion), Viridis3D, and Voxeljet. Binder jetting services are also available from 3DEO, creator of a proprietary binder jetting technology (known as Intelligent Layering), as well as many of the suppliers mentioned. How Does Binder Jetting Work? First, a recoating blade spreads a thin layer of powder over the machine's build platform. Next, the printhead (a carriage with inkjet nozzles, similar to those used in desktop 2D printers) precisely jets the binding agent into the powder according to the part's geometry. The printhead is a carriage with inkjet nozzles, similar to those used in desktop 2D printers. It deposits the binding agent. (Image courtesy of ExOne) When the binder layer is complete, the build platform lowers, and the recoating blade spreads a fresh layer of powder across the platform and top of the part being printed. The printhead binds another layer and this process repeats until the part is complete. Finally, the part is cured while still encased in powder. The entire build box is then removed from the machine and loose powder is blown away with compressed air in a controlled environment. These green parts may be processed further to impart desired porosity and mechanical properties. Because binder jetting is performed at room temperature, the process avoids dimensional distortions common to high-heat 3D printing processes, such as warping or curling. If sintering is required, only the bonded powder that forms the parts is subjected to the heat of the furnace, so leftover loose powder can be recycled without fear of degradation. What Postprocessing Is Required? Because the loose sand itself is the only support necessary for parts as they are being printed, support removal is not a typical postprocessing step for binder jetting. Many parts made via binder jetting, including sand casting cores and molds, typically require no additional processing and are ready to use in the green state after binder jetting. Green parts are sometimes infiltrated with another material to strengthen them without sintering. However, most binder jetted parts are cured and placed in a sintering furnace to bond the powder metal and burn away the binder. This burn-off method causes shrinkage that must be accounted for in part design and limits the recommended part size. The sintering process results in an average surface roughness fine enough for many end-use parts and features without further processing. Sandblasting and polishing can enhance the surface finish when necessary. Hot isostatic pressing (HIPing) may be employed to achieve high densities and reduce porosity in solid metals and some ceramics. Binder jetting enables the parallel manufacturing of multiple parts at the same time, which is why the technology is suitable for serial production of complex parts. (Image courtesy of Digital Metal) Why Use Binder Jetting? Binder jetting machines offer larger build volumes than many powder-bed 3D printing technologies and make it possible to stack multiple layers of parts on top of each other in the build box. Parts made this way can be nested within all three dimensions of the printer's build volume, enabling parallel manufacturing of multiple parts at the same time. Materials used in binder jetting tend to be more affordable and more easily recycled than those used in other powder-based AM processes, which translates to cost savings and competitive part pricing. The technology is also accurate and repeatable, making it suitable for serial production of small, precise parts. More from Additive Manufacturing on Binder Jetting 3D Printed Silicon Carbide Enables Safer Nuclear Power Generation Binder jetting provides a way to create pure silicon carbide fuel structures that can withstand the harsh environment of a nuclear reactor and provide a strong barrier against the release of radionuclides. Reusable, 3D Printed Copper Filter: The Cool Parts Show #28 In this episode of The Cool Parts Show, we learn how controlled porosity obtained through binder jetting can be applied to build metal filters capable of trapping — and even eliminating — virus particles. ExOne, Ford Motor Co. Develop Aluminum Binding Jetting Process In a project co-funded by Ford Motor Co. and the ExOne Co., a team of engineers, material scientists and manufacturing experts has developed a process for rapid and reliable binder jet 3D printing and sintering of aluminum that delivers properties comparable to die casting. Cadillac Blackwing Models Are First GM Cars Using Additive Manufacturing for Full-Scale Production Three functional components are 3D printed thanks to cost savings and design freedom. Layers lines on the shift knob signify this advance. If you're going to use AM for production, the subtractive steps deserve as much consideration as the additive cycle. There are gaps in additive manufacturing where no published standard or specification currently exists for AM to respond to a particular industry need. Learn about the resources and additive standards and make more sense of the growing technology in this sphere. When your metal part is done 3D printing, you just pull it out of the machine and start using it, right? Not even close.

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