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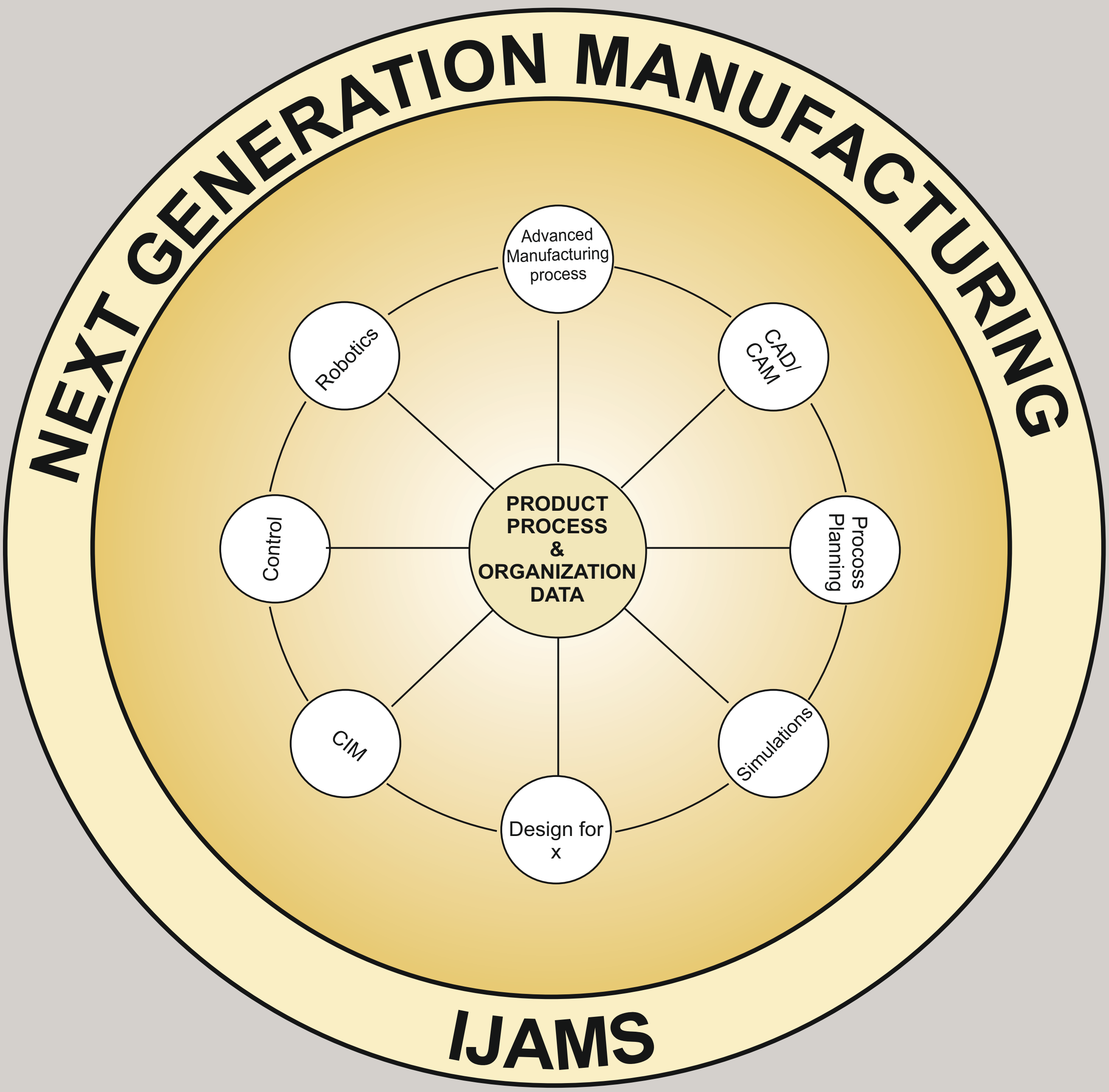

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Foreword

It is a great honor and pleasure for us to put forth the Issue 1, Volume 17 of International Journal of Advance Manufacturing Systems (IJAMS) in 2020. This issue presents three papers that were reviewed and selected from the papers submitted to the journal. These papers deal with development and implementation topics of high interest related to Agile Manufacturing. We are committed to bringing out highest quality research papers in each issue.

We wish to express our sincere gratitude to all the authors whose papers have been selected to appear in this issue. We will also make these papers available as soft copy in the journal's new web page being launched shortly. The soft copies will bring greater hit to the papers and in turn our IJAMs journals impact factor will increase. We will also produce a limited number of hard copies of the journal for individuals and libraries.

The journal quality can be improved by publishing more theoretical and application oriented papers. We also look forward to papers relevant for Industry 4.0 and collaborative manufacturing using advanced techniques and IOT. The editorial committee has decided to bring in a new section entitled Innovation and Entrepreneurship in the journal. We request all the prospective authors to send the papers for publication considerations to the chief-editor.

Dayalbagh Educational Institute was declared as one of the five cleanest Institutes of India, NAAC A+ and IIC 5 Star rated institute. It is a great honor to bring this IJAMs journal from Dayalbagh Educational Institute (DEI) campus, India.

As this volume is getting published at a time when the world's economy is disrupted on account of COVID-19 Pandemic, it is pertinent to write few lines on how innovative practices adopted at Dayalbagh have helped the institute and community. In the COVID-19 pandemic era, Dayalbagh, in its own inimitable way, has devised practical and economically viable solutions that have enabled life to go on without lockdowns and disruptions of activities. It has adopted a multi-pronged approach that includes adopting adequate social distancing and safety precautions, boosting immunity through wholesome nourishment, physical exercise, Sahaj Yoga and exposure to sunlight, adopting low cost hybrid sanitization schemes etc.

There have been no instances of COVID-19 affliction in Dayalbagh. Activities have been pursued without a single day's break. The Dayalbagh Educational Institute (Deemed to be University) has completed the previous academic session in time and completed the admission process for the current session successfully. This has been made possible through adoption of appropriate technology for online, supervised and mobile technology solutions that are affordable and available even in the remote and remotest locations of the country. Detailed treatises on the best practices followed are given at:

https://www.dei.ac.in/dei/edei/files/COVID-19%20Best%20Practices%20DEI.pdf

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HYBRID 3D METAL PRINTING

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Abstract: The goal of this research is to design, build, and test a novel and unique Hybrid 3D metal printer technology system employing both additive and subtractive processes in one unit. The system is capable of producing a high quality finished components on one setup. The Hybrid 3D metal printer technology is an integration of control and physical systems of Gas Metal Arc Welding (GMAW) unit used for material deposition and a Computer Numerically Controlled (CNC) Milling machine used for material removal. This system provides a smaller footprint and a more cost-effective way to produce complex metal parts than other competitive 3D metal printing technologies. Both 3D metal printing and machining are digitally controlled from a computer program using a standard digital interface utilizing CNC programming. As a supplementary benefit, the proposed Hybrid 3D metal printer is user-friendly; a user without additional experience than CNC machining can produce functional, high-quality products.

Keywords: Three dimensional printing, hybrid metal printing, additive manufacturing, CNC machining

1. Introduction

1.1. Background

The most common 3D (three dimensional) printing technology (also known as Additive Manufacturing) has been developed around plastics and is still a relatively new technology. While there are many options in 3D printing plastics, metal 3D printing, with a few exceptions, has been confined mainly to costly pieces of equipment like one used in the airspace and jet propulsion industries [1].

Presently there are two fundamental 3-D metal technologies to build a part layer-upon-layer. Laser sintering of metal powder and direct metal deposition using laser/high energy beam to melt powder on a metal substrate, to create a part layer-by-layer. Parts made with either technique require using of support material to fabricate complex structures (overhang, bridges), secondary operations (follow on machining to achieve part tolerance and surface finishes), and additional labor to make the final product. The high cost of equipment and material, size limitations, maintenance and operation cost, and the extra added cost for secondary machining and finishing operation limit's their application to low volume, high-cost parts used in industries like airspace [2, 3, 4]. These high-capital and operating costs of present 3D metal printing technology prevent many manufacturers from adopting it. There are few hybrid 3D metal printing systems based on CNC manufacturers like DMG MORI, ELB-Schliff, Matsuura, Mazak, Mitsui Seiki, and Okuma and several new ones such as Diversified Machine Systems, Fabrisonic, and Optomec [4, 5].

Other companies such as Hybrid Manufacturing Technologies (HMT) and 3D-Hybrid Solutions, Inc. also provide add on solutions to CNC machines. Most of the 3d metal printing systems are based on laser sintering or direct metal deposition to create a 3D printed part at first, and then they are machined on the same or different equipment. Only a few systems use GMAW (also known as MIG- metal inert gas) welding for deposition, similar to our process [3, 4, 5]. Essentially, both groups metal powder and hybrid technologies completed the 3D printed parts first and machined them after that. These technologies pose several disadvantages with performance, quality, and cost. The cost of the machine, material, and maintenance is prohibitively high (starting from several hundred thousand to millions of dollars), and performance speed is quite low. Both groups could not produce complex overhang geometry without the support structure and provide in-situ layer control of building geometry, and surface finishes when machining each layer. We believe our system has several unique advantages in comparison with other technologies. It is capable of producing high-quality functional parts, with complex geometries, tight tolerance, and superior finish on the same machine while providing lower material and operation costs.

1.2. Additive and subtractive manufacturing

At present 3D printing, now called additive manufacturing (AM), is one of the fastest-growing manufacturing systems. The widespread became the usage is simple. It is often called 3D printing, implying that it is an extension of the 2D printing in one more dimension to produce 3D objects. Additive manufacturing is a type of so-called 3D printing process when a material is added layer by layer to build a 3D structure. We will explain this general process to reveal the difference with the proposed system described later. The explosive increase of the 3D printer usage is based on the fact that everybody, without any engineering knowledge, can produce their object, at relatively low cost, anytime at any place, and mostly at home. Another factor for extensive usage is that the AM type 3D printers and materials costs became very affordable.

1.3. Proposed 3D Metal Printing/Machining

Traditional AM has many limitations, such as materials, mostly plastics, small working volume, and low quality, which could not even get closer to industrial quality products. Looking at the advantages and limitations of AM and subtractive manufacturing processes, we developed a new method to take the best of both processes without drawbacks. To distinguish our process from traditional AM and subtractive manufacturing (mostly metal cutting), we call our system Hybrid 3D metal printing that combines both methods.

Earlier research and knowledge are readily available to 3D metal printing materials and successfully applied in industry. There are many examples of successful applications of 3D metal printing like aircraft parts, Airbus titanium pylon bracket [6], engine parts by Mercedes [7], and WV [8], and Metal Jet fuel nozzles by GE [9]. Our hybrid 3D metal printer allows the building of additive/subtractive machines based on existing well-know and developed technologies GMAW welding and CNC machining, to deliver finished, ready to use parts, [10]. It can extend the existing machine shops to 3D printing advantage while still keeping its original operation capabilities.

2. Methodology

2.1. Feasibility study and testing of the 3D metal printing/machining system concept

Initially, we defined parameters for a 3D metal printer with machining capability as an alternative to the more expensive options currently available. This machine can deposit and remove metal material to create a work piece. This technology follows the 3D design created using a 3D solid modeling application, crates a program, and uploads it to the 3D printer to produce functional parts. The machine can withstand higher temperatures needed to work with molted metals while maintaining the desired accuracy in machining. A set of specifications was created to keep the project on track, and a set of benchmarks tests were accomplished.

We had investigated suitable metal 3D printing technology for metal deposition. We examined several methods for 3D metal printing to deliver material layer by layer. We found that one common way to deposit build material is gas metal arc welding (GMAW), commonly called metal inert gas (MIG) welding. It provides a sufficient method to build the material structure but lacks a building precision. Initially, we developed and built a simple prototype machine using MIG welding and machining controlled by a CNC machine. Although the testing process and the prototype machine were not fully automated completed, we successfully produce good quality samples. This proof of the concept prototype facilitated us to refine the concept to build a system to function automatically.

2.2. Hybrid 3D metal welding/machining process interleave method

The operation process of the 3D metal printing/machining system is as follows. At the initial stage of the process, a 3D CAD solid model is used in CAM software to create the models of the additive (metal deposition) and subtractive (CNC machining) program.

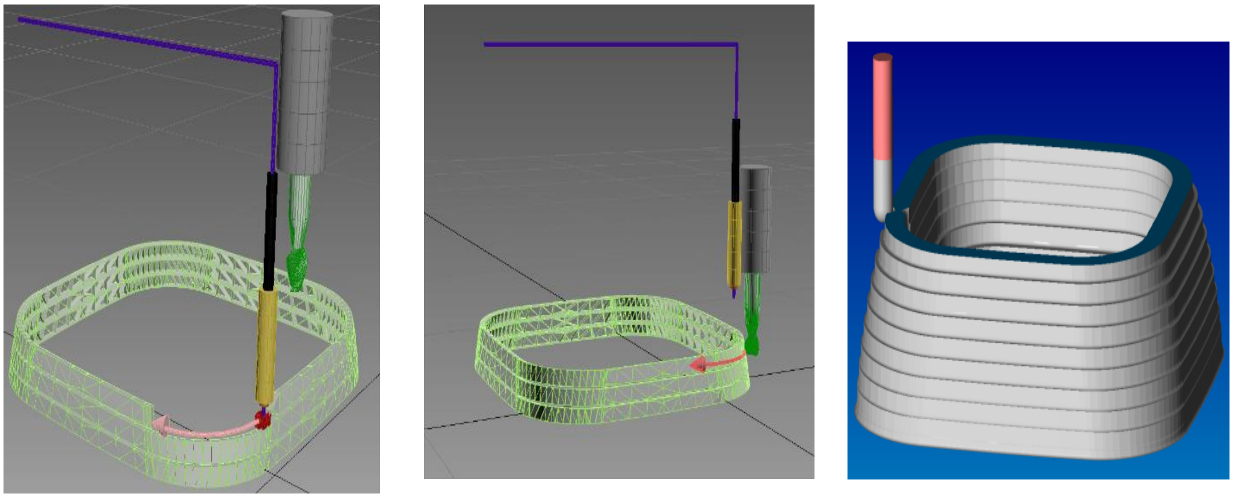

Figure 1: 3D metal printing (left) and machining processes

The Hybrid 3D printing process start after the program is loaded in the CNC system. At first, the tool with the welding head is moved in the position and deposits a thin layer of material on the substrate plate, see Figure 1 (left). The welding head movement is controlled by the CNC machine, while the welding parameters are controlled by the GMAW welder. After a layer is completed, the welding head retracts, and the cutting tool machined the layer sides following the programmed CNC path, (Figure 1) (middle and right). This process is repeated multiple times to finish the production of a part.

During the initial testing stage, we discovered that for some basic shapes, the 3D printer worked great. Although, when producing complex shapes with overhang, hollow parts, and bridges, the molted metal tends to overflow, and the sound quality could not be effortlessly achieved. We went back to refine the concept and redesigned the initial prototype to avoid these problems.

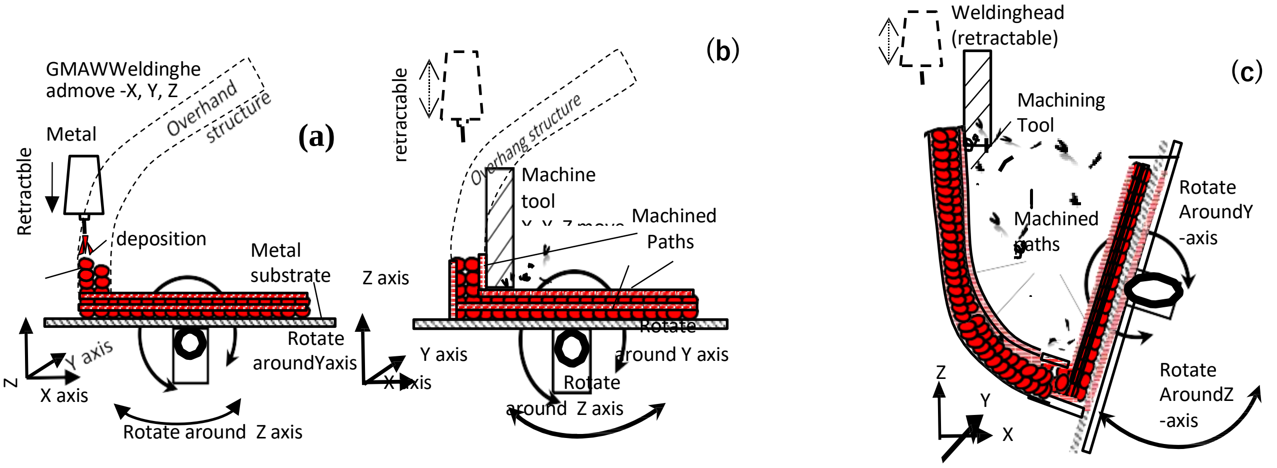

Figure2 (a, b, c): 5 axis hybrid 3D printing-MIG welding deposition and CNC machining of overhang structure

2.3. The new Hybrid 3D metal printing system

A novel 3-D metal printing device and process were developed and built at Western Michigan University. This device combines GMAW welding technology (also known as MIG) with Computer Numerical Controlled (CNC) Machining. We integrate additive welding technology (the build-up of metal layers) with the subtractive/machining capabilities of CNC machines to create a unique ability for 3D component fabrication, feature addition, and repair for a wide variety of metals and metal alloys. The machine's synchronous 5 axes, linear (3), and rotational (2) motions provide precise control of both additive delivery and machining of each layer from start to finish, see Figure2. The attached retractable welding arm is guided by the CNC controller to deposit metal precisely on a predefined path for each layer; then, the CNC machining tool removes excess material from the deposited layer. This deposition welding (additive) and machining processes (subtractive) is repeated multiple times until the final part is produced. Our hybrid system has the unique feature that it can deposit material and machine it in 5 axes, to create complex shapes, including overhang, bridges, and holes without supporting material (Figure 2). The milling passes are capable of achieving high accuracy and surface finish on any surface in any direction without any additional setup or adjustment. Because the deposition process utilizes standard welding wire, the operating cost of our hybrid technology is relatively low, without requirements for special materials or training, resulting in a low cost per part production.

2.4. Hybrid 3D Metal printing prototype

We are creating a hybrid additive, and subtractive interleave process and build our first Hybrid 3D metal printing prototype from scratch. All these operations are performed on the same setup, (Figure 3).

Figure 3: Hybrid 3D Metal printing prototype

The Hybrid 3D metal printing machine can produce functional parts, without using any support structure, in the one setup with high tolerance, same as CNC machining, while reduced manufacturing time and cost.

3. Results and Discussion

Our hybrid technology eliminates the additional steps and costs of machining parts on separate stations, e.g., machining immediately after each layer of metal is deposited. It enables the manufacture of 3D printed parts with complex geometries (including overhangs and cavities) without using support structures—required with existing 3-D metal printing technologies.

We are creating a hybrid additive and subtractive interleave process for our Hybrid 3D metal printing technology using CAM software to create the automation program. All these operations are performed on the same setup and without using any support structure.

3.1. 3D Metal printing problems and our solution

There are several problems that other 3D metal printing technology has, such as overhang/hollow structures, low-quality surface finish, and tolerance, etc. For example, existing 3D metal printers design with an overhang structure greater than 0.020 inch (0.5mm) requires additional support to prevent damage to the part [11], (Figure 4).

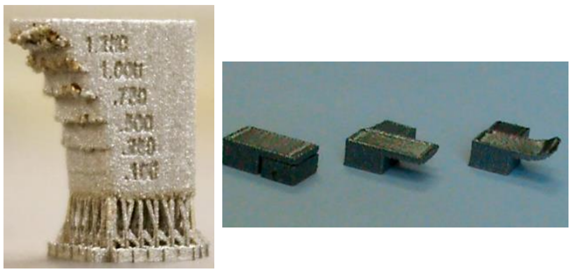

Figure 4: Existing metal 3D printing problems-overhang structures [11].

Our technology provides capabilities, in addition to three linear motions, to rotate the table to any angle to create effortless overhang structures without support that are also precisely machined, (Figure 5).

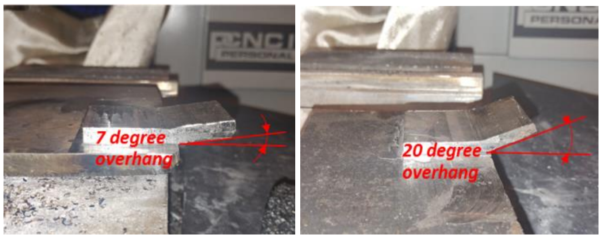

Figure 5: Hybrid technology allow 3D print and machining without any overhang

Other problems for 3D printing are producing complex overhand structures such as bridges - flat down-facing surfaces supported by two or more features with minimum unsupported -0.080 inch(2mm) and holes (Figure 6.) and channels not exceed a diameter of 0.30 inch (8mm), [11].

Figure 6: Existing metal 3D printing -bridges and complex structure [11]

Again our technology proved that we can build not only simple overhang structures, like single bridges or even multi-story bridges, (Figure 7).

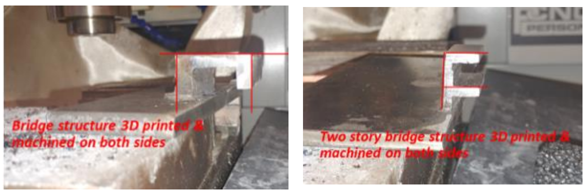

Figure 7: Hybrid technology allows 3D print and machining single or multi-store bridges

Furthermore, we can produce parts with intricate geometry and inner surfaces normally unreachable by any CNC machining tool, (Figures 8 and 9).

Figure 8: Hybrid 3D printing aluminum of spiral surface machined inside/outside

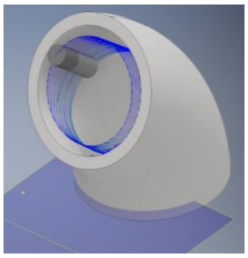

Figure 9: Hybrid 3D design of toroidal surface machined inside/outside

In general, existing 3D metal printing technology produces inferior quality parts with relatively low tolerances for metal 3D printing features +/- 0.020 inches (0.5mm); furthermore, the printed surface finish is very low that made produced parts impossible to assemble [12]. To make parts functional, secondary machining, on separate machines and setup, are required to remove support structures and provide suitable tolerance and surface finish.

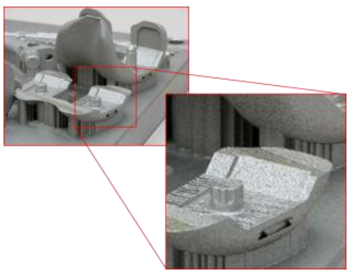

Figure 10: Existing metal 3D printing quality problems- removing support structure, tolerance, surface finish [12,13].

Our Hybrid 3D metal printing technology provides the same quality as CNC machining with tolerances in range 0.001 to 0.0001 in and superior finish, all on the same machine and setup (Figure 11).

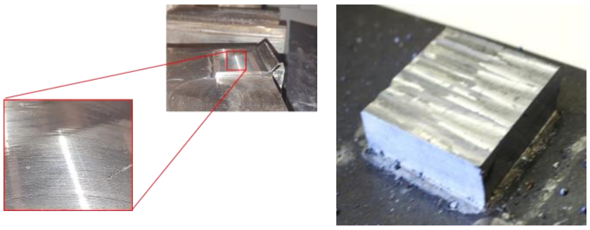

Figure 11: Hybrid 3D metal printing delivers same quality as CN**C** machining process

3.2. Hybrid 3D metal printer result and testing

We have created a hybrid additive and subtractive process for our Hybrid 3D metal printing technology using CAD/CAM software that can produce:

- High quality finished parts:
- All additive/subtractive operations are performed on the same setup with superior CNC quality.
- Complex geometry without support material:
- Our technology allows the production of finished machined parts with complex 3D geometry on the same machine, without the need for any support structure.
- Structures with isotropic properties in any direction:
- Our machine can deposit and subtract metal in any direction utilizing 3 linear axes and 2 rotational axes. We have produced samples by adding metal, layer by layer, in specific patterns: along the X-axis direction, across Y-axis, at 45°angle, and vertical Z-axis (Figure 12) and have tested the mechanical and microstructural properties using destructive and non-destructive methods. The results show almost identical isotropic mechanical properties, metallurgical properties, and superior surface finish in all directions [14].
- Testing process and optimization:

- We proved that our Hybrid 3D metal printing technology could produce complex geometry parts with precision dimensional accuracy, meeting the design specifications.

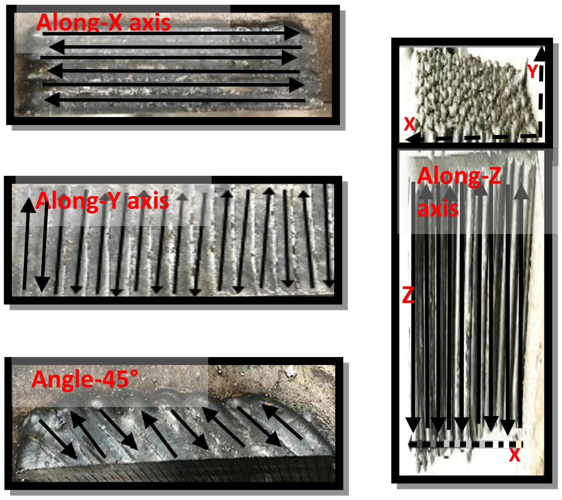

Figure 12: Hybrid 3D printing layers' directions: along X axis, across Y axis, at angle 45°, and vertical Z axis.

Furthermore, we have tested and evaluated that the Hybrid process is capable of fabricating fully dense metal parts, isotropic in all directions with mechanical properties better than bar stock material.

For example, the average yield (YTS) and ultimate (UTS) tensile strength of 3D printed tensile specimens is 395MPa and 500MPa, which are better compared to standard AISI 1018 mild/low carbon steel (YTS 370MPa & 440MPa). The Rockwell B (90-98) and Brinell hardness (170-178) numbers are also better than AISI 1018 mild/low carbon steel (HRB 71 and Brinell 126), for more details refer to results listed in our publication [14].

Built parts for industry: We have made multiple complex geometry parts with a superior surface finish and tight tolerances. These sample parts are 3D printed and machined on the same setup. Most of these parts were made for industrial customers who successfully tested them inside their equipment, (Figure 13).

Figure 13: Sample parts produced for industrial customer.

We had proved that the Hybrid 3D metal printing machine could produce functional parts in the same setup with high tolerance, same as CNC machining, while reduced manufacturing time and cost. This hybrid concept can be effortlessly incorporated as add on kit to new or convert existing any CNC machine to a hybrid 3D metal printer. It can produce metal parts without the need for special training for the operator while still retaining the original machining capabilities.

4. Conclusions

We completed and tested the functionality of the Hybrid 3D metal printing/machining prototype system. One of the best advantages of the proposed technology its capability to produce high quality finished functional parts in one setup. The advantage of using the hybrid 3D printing process and machining is that the quality of every layer is controlled precisely, thus make it possible creating of finished complex surfaces, isotropic in all directions, with intricate internal and external shapes. Such achievement cannot be accomplished with traditional CNC machines or 3D printers. In contrast to the metal powder-based technologies used by other 3D metal printers, the material used in this technology, GMAW welding wire, is broadly commercially available produced in large quantities and doesn't need special requirements for storage and operation. This Hybrid technology is significantly lower in initial cost and cost to operate. It has a small facility footprint as it constitutes nothing more than an add-on accessory to a new or an existing CNC machine.

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Biography

Dr. Pavel Ikonomov is an associate professor at Western Michigan University, Kalamazoo, Michigan, USA, since 2003. He has a Ph. D. degree in Precision Engineering, System and Inf. Engineering from Hokkaido University, Sapporo, Japan. He has been an assistant professor at the Technical University of Varna, Bulgaria, visiting professor at Tokyo Metropolitan Institute of Technology, UCLA, and NIST, CTO of Virtual Reality Centere Yokohama, Japan, and chief scientific officer of hybrid 3D metal printingstartup 3DASH Technology, USA.

He has more than 160 referenced publications in journals and conferences proceeding, nine books, and three patents. He is chair of the 116 chapter of SME-USA, and a member of JSPE, JSME, ASME, SME, ASEE, AEE, and International Society of Agile Manufacturing (ISAM). He is also an associate editor of the International Journal of Advanced Manufacturing Systems (IJAMS). He has more than 35 years research experience in the areas of CAD/CAM, Virtual Reality simulation for industrial application, 3D printing, precision machining, and robotics, Immerse technologies, nanotechnology: virtual assembly using force feedback for micro and nanometer assembly control; tolerance modeling and inspection with Coordinate Measuring machine, free form surfaces design and CNC machining, process planning, component grouping, design of manufacturing systems, project management, Concurrent Engineering, client/server computing. Wireless Internet for mobile industrial applications. Extensive computer experience with a wide range of CAD/CAM, Computer-Aided Process Planning (CAPP), 3D data exchange, and system development tools. He expertizes in AR/VR simulations, Hybrid 3D metal printing, IoT and digital manufacturing technologies, Industry 4.0, and smart manufacturing.

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CHARACTERIZATION OF THE MECHANICAL PROPERTIES OF PARTS PRODUCES WITH A HYBRID 3D METAL PRINTER

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Abstract: 3D printing, also known as Additive manufacturing and rapid prototyping in the past, has been growing exponentially in reset years. While plastic 3D printing is widely used, 3D metal printing has limited applications due to several factors. This technology needs to be tested and compared with existing metal fabrication technology to make functional metal parts. We will discuss testing the physical, mechanical, and metallurgical properties of the parts produced with the Hybrid 3D metal printer. Our printer uses GMAW welding and CNC machining, two widely used methods in industry-developed to a novel hybrid system that can produce a part in one setup. We did our testing following the regulation by ASTM and ISO 3D printing standards and NIST Additive Manufacturing Benchmark Test Series (AM-Bench). We used standard methods to evaluate tensile and bending strength, hardness test, micrograph with optical and microscale laser microscopes, surface rouges, CT X-ray scan, and laser and white light 3D scanning. The result proved that our technology could produce parts with mechanical properties exceeding the standard wrought metal products.

Keywords: Three dimensional printing, mechanical properties, hybrid metal printing, additive manufacturing, characterization

1. Introduction

Additive Manufacturing (AM), also called 3D printing, has been primarily focused on thermoplastic components but is rapidly growing to include metal 3D parts. Powder bed fusion, binder jetting, direct energy deposition, and material extrusion are the most common technologies employed for producing 3D metal parts. Based on the 3D printing method, metal parts are produces differ in their quality, size, cost, and mechanical properties.

1.1 Metal 3D printing technology

MBF: One of the 3D printing technologies, metal powder bed fusion (MBF), includes three subtypes: direct metal laser sintering (DMLS), selective laser melting (SLM), and electron beam melting (EBM). SLS technology works by spreading a thin layer of powder on a flat surface; the power laser/beam melt it the desired path; the process is repeated multiple times to complete the part. Depends on the technique, SLS and DMLS can create parts by implementing sintering or melting. SLS is using one metal when DSLM metal alloys. Sintering produces parts with porosity and needs a heat treatment after the print to melt and joint particle; therefore, they could not reach the density and mechanical properties of the solid metal. At present most of the SLS and DMLS machines use melting. Instead of a laser, EMB employs a high-power electronic beam that makes them capable of printing with high-temperature metal alloys [1].

MBF advantages pose advantages such as using various metals and alloys, mechanical properties matching wrought metal, and processing are the same as regular metal parts. The disadvantages are that parts need designed support structures and build plates, require additional secondary operations to remove excess material, prints are small sizes, and uses expensive machines, operations, and metal powder [2].

MBT: Another 3D printing technology, Metal Binder Jetting (MBT), uses an inkjet-based process spraying binder onto the metal powder. It is based on the technology developed at MIT in ’90 s, then called 3D printing [1]. MBT process starts with spreading a thin layer of powder (similar to SLS). Then, the inkjet head sprays binder on the powder, and the process is repeated to create a fragile part. To produce solid parts, rebinding and sintering using a furnace are required. This method has several advantages, such as producing large parts, deliver very fact printing, it is cheaper than PBF, does not need support structures, and build plate.

DED: The third 3D printing technology, Direct Energy Deposition (DED), has two sub-types laser engineered net shaping (LENS) and direct metal deposition (DMD). DED prints by melting, with laser, electronic beam or arc, metal powder, or wire on a metal build substrate. The way it works is similar to welding [1]. The advantages of DED are large sizes, efficient material usages, fast printing, solid wrought like metal with good mechanical properties, and most inexpensive material (if a metal wire is used). Disadvantages include low surface quality and details resolution, which require machining, require support material, and uses expensive machines and operation [2].

MME: The fourth method is Metal Material Extrusion (MME), which works similar to Fused Deposition Modeling (FDM), producing parts using plastic filament or rod with embedded metal powder. Solid parts are produced by sintering the printed parts in a furnace [3]. Advantages of this technology are that produce the most inexpensive 3D printing parts, and it is easy to operate. Disadvantages are high porosity and lower mechanical properties, require debinding and sintering, precision, and geometry restrictions related to shrinkage during sintering [2, 3].

Current 3D metal printing methods present several problems, including inconsistent material structure, uses multiple specialized chambers, uses systems expensive to purchase, install, operate, and maintain. Furthermore, these methods require additional support structures that need secondary operations to remove excess material to meet tolerance requirement and surface finish. These challenges call for an innovative 3D metal printing device that is simple, inexpensive, and easy to operate.

1.2 Hybrid 3D Metal Printing Technology

A novel 3-D metal printing device and process were developed and built at Western Michigan University [4]. This device marries Gas Metal Arc Welding (GMAW, also known as Metal Inert Gas MIG) with Computer Numerical Controlled (CNC) Machining. It integrates additive welding technology (the build-up of metal layers) with the subtractive/machining capabilities of CNC machines. The CNC controller guides the welding arm to precisely deposit metal on a predefined path for each layer; then, the CNC machining tool removes unwanted material after depositing each additive layer. This deposition welding (additive) and machining processes (subtractive) is repeated multiple times until the part is produced. This process of integrating additive with is subtractive processes enables the fabrication of complex geometries (e.g., overhangs, cavities) without using support structures usually required by other AM technologies.

The innovative hybrid 3D metal printing technology fulfills the industry's needs for an economical, zero-footprint solution for the rapid fabrication of complex metal components. The hybrid 3D metal printer technology can be incorporated directly onto new or existing standard CNC mills already a part of a machine shop, with near-zero incremental footprint to the facility, and utilizes standard commercial welding wire as the raw material input.

Advantages of this approach to metallic Additive Manufacturing include lower capital cost, smallest footprint, lower operating cost, unlimited scalability, and inherently full density printed components with final form and finish directly from the machine without the need for secondary operations. Commercial applications include manufacturing plants, maintenance shops, and isolated remote fabrication/repair facilities.

2. Methodology

2.1 Why extensive testing is needed

To make 3D printing the next stage in the new technology, there is a need to prove that it can meet the requirement regarding material quality. The 3D metal printing poses new challenges regarding the testing of the material structure of the parts produced with our hybrid methods. Casting, welding, and machining are well-established processes with a clear path for testing material structures and mechanical properties. The hybrid 3D metal printing process and its products, which can be considered as a combination of these elements of three technologies, is completely new and not well investigated. Due to the intensive heating-cooling process during metal deposition, tiny defects such as pores or cracks can appear in the layers reducing the mechanical properties of the part. For example, when layers are deposited over each other as they cool, residual stress can accumulate, creating cracks between some layers and even wrapping the surfaces. Therefore, the 3D metal printing process requires superior control to avoid defect and changes within the internal structures of the material and material properties need to be tested thoroughly.

3D printing parts, depending on the process parameters, can have anisotropic properties [5, 6]. For example, depending on the direction of the deposition of material, most 3D printed produce layers with isotropic properties in XY direction, but the properties in the Z direction are lower. These properties also depend on the delivery path directions, layers width, and thickness. For example, a structure may be different for the material delivered on the X-axis direction, from one delivered on a crossways pattern along Y-axis (90^{o} degree to X), from one delivered at 45^{o} degree, and significantly different on the vertical Z-axis (Figure1.)

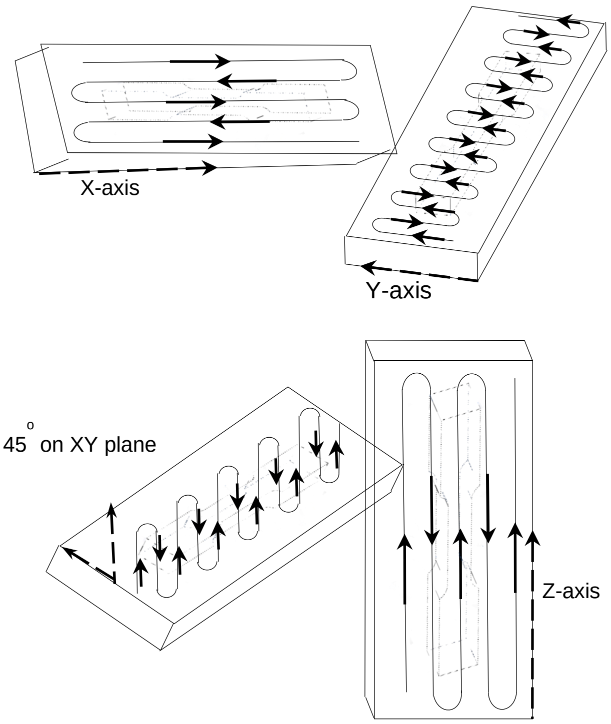

Figure 1: Deposition directions: along on X –axis, across on Y-axis, on 45^{o}, and on vertical Z-axis

Many governments and industry standards are in progress of development to ensure that 3D metal printer parts are testing to meet industrial requirements. As discussed at ASTM and NIST, a workshop May 4-5, 2016, there are metal additive manufacturing (AM) products applications where fatigue and fracture are critical [7]. NASA is well known for its pioneer efforts in AM implementation and usage while applying strict standards requirements for any product used in the space industry [7, 8].The draft NASA MSFN standard lists “four fundamentals aspects for process control of AM ”to achieve products with reliable mechanical properties: Metallurgical Process Control, Part Process Control Equipment Process Control, and Build Vendor Process Control.” According to these standards, the AM produces unique material products from each AM machine, so the process needs to be qualified separately. Witness samples allow testing without handling the actual part, to ensure the 3D metal printing process is accurate before moving forward with the actual product. Witness specimens provide direct evidence only for the systemic health of the 3D printing processes during the witnessed build [8].To meet the requirement of the industry, AM and in particular our hybrid metal 3D printing process, rigor standard requirements need to meet when building products.

2.2 Testing of 3D printed products

Samples produced with our hybrid 3D metal printer need to be tested to meet requirements for quality parts. Apart from the dimension and tolerance requirement to be met by the production, we decide to perform the following tests [9].

2.2.1 Destructive testing

Tensile testing: a tensile test measures the strength of a 3D metal printed and machined sample locate midway between the jaws of the testing machine. The width thickness of the test specimen is measured before testing. The tensile strength is calculated by divide the load by the cross-section area of the middle of the sample. b. The shearing strength of transverse and longitudinal fillet welds is determined by tensile stress on the test specimens. The shearing strength of the weld in pounds per linear inch is determined by dividing the maximum load by the length of fillet weld that ruptured [10,11].

Bend testing: It provides values for the modulus of elasticity in bending, flexural stress, flexural strain, and the flexural stress-strain response of the material. It deforms the test material at the midpoint forming a bend without fracture [10].

Hardness testing: Hardness is the resistance to indentation, and it is determined by measuring the permanent depth of the indentation. The indentation hardness value is obtained by measuring the depth or the area of the indentation using a ball-shaped indenter for the Brinell hardness test or cone for the Rockwell test. Appropriate methods will be selected depending on the welding materials and heat treatment [10].

Macro etching testing: The acid reacts with cracks edges and accentuates the weld defects. Small samples are polished and then etched. The cracks are inspected visually and measured for lack of fusion, porosity, cracks, and others. [10,11].

2.2.2 Nondestructive testing

Liquid penetrant testing: is also called dye penetrant inspection. It is one of the most commonly used crack detection methods for of surface-breaking discontinuities. It can reveal discontinuities problems or pores internal to the weld. There are two methods, using the so-called visible die or fluorescent dye. For the visible die, a colored die is used with a white developer to increase the contrast and make it visible under regular light. Similarly, when the fluorescent dye is applied, the developed is applied later to increase penetration to the surface imperfections. A black-light is then used to highlight the contrast between the fluorescent material and the sample reveals the defects [12, 13].

Magnetic particle testing: is used to detect cracks, porosity, seams, inclusions, lack of fusion, surface discontinuities, and shallow subsurface discontinuities in ferromagnetic materials. When applying a magnetic field to a part, it attracts the magnetic particles to the crack or imperfection places [10, 12].

CT X-Ray testing: is a radiographic test method used to reveal the presence and nature of internal defects in a weld, such as cracks, slag, blowholes, and zones where proper fusion is lacking. Gamma provides deeper penetration allowing thicker walls to be inspected but is slower [12-13].

2.2.3 Metallurgical testing

Although the metallurgical tested will be performed during the project, the information for grain size, expected phases or carbide sizes, grain boundary cleanliness, porosity, lack of fusion/cracks were used to correlate these results with the one investigated by this research.

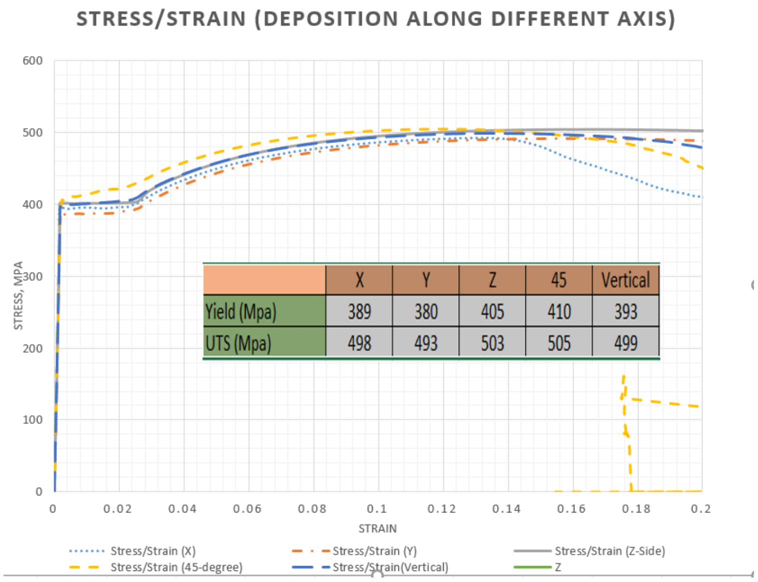

Figure 2: Tensile testing X, Y, Z, 45 degrees and side directions of material delivery

3. Results and discussion

3.1 Destructive testing

We have optimized the 3D printing and CNC machining during the technology development and testing, so our final results show no cracks, porosity, and imperfection on any samples. They were produced with different directions of the 3D printing welding delivery: along the X-axis, across on Y axis, under 45 degrees, along the Z-axis sideways, and vertical along the Z-axis. The testing proved that our technology provides the same mechanical properties (isotropy properties of the material) in all directions.

<u>*Tensile testing:*</u> The test samples were prepared as per ASTM E8/E8M-16a standards [14]. Sub-sized specimens were used, with dimensions of 100x6x6 mm (LxWxH). Twenty-five samples we created for each direction, X, Y, Z, 45o degree, and vertical side, of materials delivery. The shield gas ratios used were Argon30%/$C0_2$70%. After each layer was delivered, the top was machined to produce a smooth surface for the next layer. This process assured the quality of the welding and the constant height of the delivery pattern.

We tested more than 125 tensile samples using disposition the specified above five different directions of the welding material deposition. According to the results, the average yield & ultimate tensile strength for all directions of deposition is 395 MPa and 500MPa, respectively (Figure 2.)

According to ER70S-6 Gas Metal Arc Welding (GMAW) wire technical specification sheet, ultimate strength, and yield strength are 586 MPa and 483 MPa, respectively [15. In addition to wire material properties, we compared our 3D printed test results with ASTM A36 Mild/Low Carbon Steel [16], which has the yield and ultimate tensile strength between 380 MPa and 505 MPa, respectively. The result shows that our 3D printed samples have the same or better tensile properties when compared with GMAW welding wire MDS specifications and higher than ASTM A36 Mild/Low Carbon Steel. The test also confirms the isotropic mechanical properties of the parts produced with this technology. There was not much difference in the tensile properties when metal was a deposit in a different direction.

<u>*Bend tests:*</u> It provides values for the modulus of elasticity in bending, flexural stress, flexural strain, and the flexural stress-strain response of

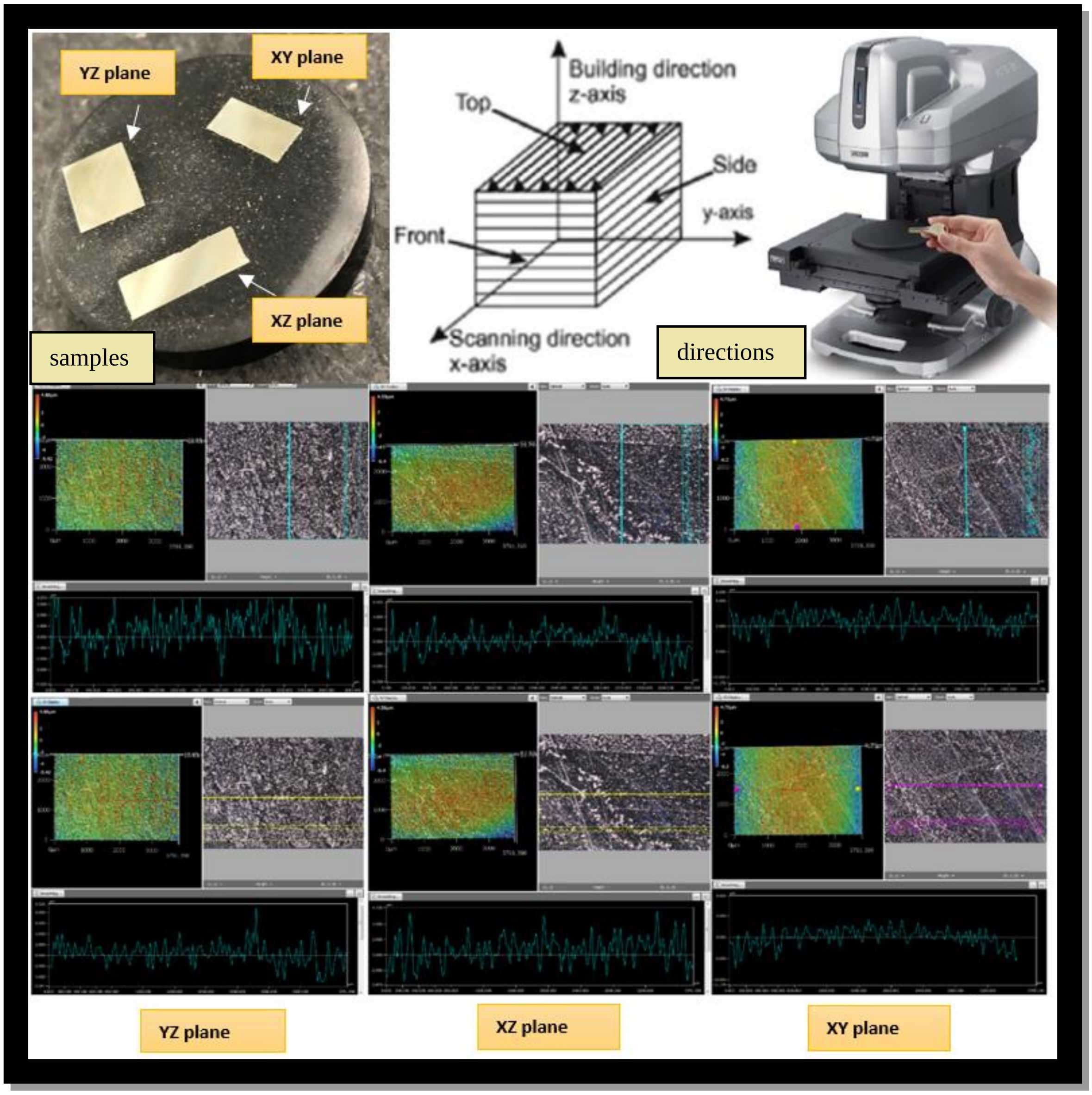

Figure 3: 3D surface finish and deviations in micrometers

the material. Our 3D printed samples have identical or better bending properties when compared with ASTM A36 Mild/Low Carbon Steel.

Hardness testing: Our 3D printed samples (Average Brinell 173, Hardeners Rockwell B 94.8, Hardeners Rockwell C 65, have identical or better hardness properties compared with GMAW welding wire MDS specifications and higher than ASTM A36 Mild/Low Carbon Steel [10, 16, 17].

3.2 Nondestructive testing

Liquid penetrant testing: Liquid penetrant testing, also called dye penetrant inspection, is one of the most commonly used crack detection methods for surface-breaking discontinuities [17, 18]. We applied for liquid penetrant Cantesco D101-A dye penetrant developer, and Cantesco P301W-A white visible dye penetrant. We found that the common deposition approach, when welding layers were deposit directly on the previous one, the 3D metal printer may produce cracks or pores between layers, mostly due to incomplete overlapping of the weld bids or imperfect weld penetration. Therefore, we designed the hybrid 3D printing process that includes machining each layer before deposing the new layer, and we did not observe any cracks or pores.

3.3 Metallurgical testing

The metallurgical microstructure was performed to check the grain boundary cleanliness, porosity, and lack of fusion/cracks to check the quality of our hybrid technology [19]. Samples we cut into three planes XY, YZ, and XZ for printing X, Y, Z, 45^{o} direction.

First, the microstructure testing was performed using Nikon optical microscope with x400, x1,000, and x1,500 magnifications, and no porosity, cracks, and other imperfection were found.

Also, Keynce MicroscopeVR-3000 with resolution 1 µm was used to measure the3D surface imperfection of the samples. Roughness, flatness, form, contour deviations, and 3D analysis functions, such as height differences, area, volume, and roughness, were performed. Again not pores and cracks were found on any sample. The roughness from the 3D metal printing and machining is the same as after a standard CNC milling process. Depending on the cutting speed and federate, the average measure Ra values were 0.57 µm (between 16 and 32 µin.), (Figure 3.)

CT X-ray scans: CT X-ray scans were performed on several parts before delivering them to the user. No imperfection such as crack, cavity, and porosity was observed (Figure 4.)

Finally, a new digital Keynce Microscope VHX-7000 series with magnification up to 6000 times

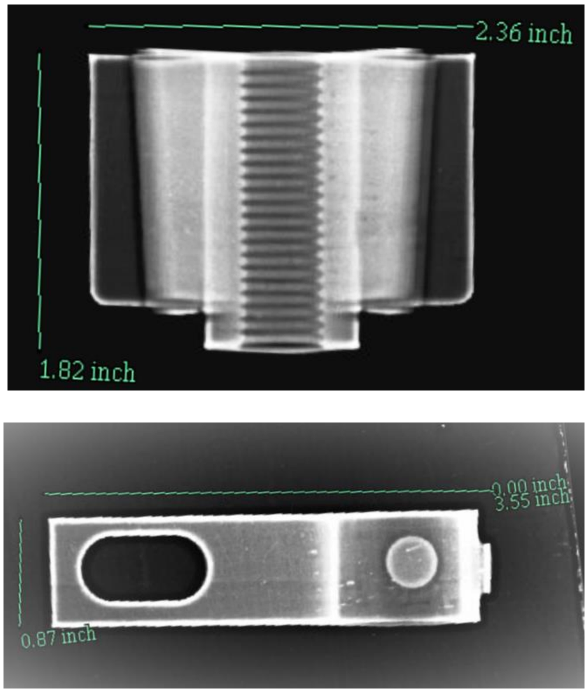

Figure 4: CT X-ray scans of parts #2 and #1 produced for a company

and resolution of 0.5 microns was used to measure 3D printed surfaces.

No cracks, pores, cavity are observed on any measured surface. The only visible imperfections noticed were few microns elevated surface bumps left from the tool marks after machining the surface of the samples.

The overall testing results proved that the hybrid technology we developed could produce functional parts with isotropic mechanical properties, superior internal/external structures, and surface finish.

4. Conclusion

We have developed and tested the performance of our novel Hybrid 3D metal printer system that can produce quality parts in one setup. Testing was performed following the requirements of existing ASTM and ISO standards for 3D printing and the NIST Additive Manufacturing Benchmark Test

Series (AM-Bench). We optimized our process to produce multiple samples in multiple delivery directions (X, Y, Z, 45o) to teste the mechanical and metallurgical properties. We evaluated properties using tensile and bending strength, hardness test, micrograph structures with optical and microscale laser microscopes, surface roughness, CT X-ray scanning, laser, and white light 3D scanning. The result proved that our technology could produce parts with superior isotropic mechanical properties exceeding the standard wrought metal products.

We have produced multiple parts for several companies that are successfully using. The testing and real applications' results prove that our hybrid 3D metal printing technology is ready for industrial application.

Future work to be done includes optimizing of the Hybrid 3D metal printing process, adding sensor based closed-loop feedback capabilities, and testing other all available GMAW wieldable materials.

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Biography

Dr. Pavel Ikonomov is an associate professor at Western Michigan University, Kalamazoo, Michigan, USA, since 2003. He has a Ph. D. degree in Precision Engineering, System and Inf. Engineering from Hokkaido University, Sapporo, Japan. He has been an assistant professor at the Technical University of Varna, Bulgaria, visiting professor at Tokyo Metropolitan Institute of Technology, UCLA, and NIST, CTO of Virtual Reality Centere Yokohama, Japan, and chief scientific officer of hybrid 3D metal printingstartup 3DASH Technology, USA. He has more than 160 referenced publications in journals and conferences proceeding, nine books, and three patents. He is chair of the 116 chapter of SME-USA, and a member of JSPE, JSME, ASME, SME, ASEE, AEE, and International Society of Agile Manufacturing (ISAM). He is also an associate editor of the International Journal of Advanced Manufacturing Systems (IJAMS). He has more than 35 years research experience in the areas of CAD/CAM, Virtual Reality simulation for industrial application, 3D printing, precision machining, and robotics, Immerse technologies, nanotechnology: virtual assembly using force feedback for micro and nanometer assembly control; tolerance modeling and inspection with Coordinate Measuring machine, free form surfaces design and CNC machining, process planning, component grouping, design of manufacturing systems, project management, Concurrent Engineering, client/server computing. Wireless Internet for mobile industrial applications. Extensive computer experience with a wide range of CAD/CAM, Computer-Aided Process Planning (CAPP), 3D data exchange, and system development tools. He expertizes in AR/VR simulations, Hybrid 3D metal printing, IoT and digital manufacturing technologies, Industry 4.0, and smart manufacturing.

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AGILE MANUFACTURING: AN IT PERSPECTIVE

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Abstract: An organization's success depends on how it responds against turbulent environment changes, demand fluctuations, hyper competition by their rivals, technological advancement and respond readily for these changes to perform well and this is where the term Agile originates. In this paper, we describe role of information technology/service sector in manufacturing industry's agility and how it has / is / will be continuously creating outstanding results. The agility of an enterprise/industry can be broken down into two main criteria- (a) Sensing (b) Responding. We have discussed the following topics in this paper: 1. How was the manufacturing industry before the introduction of IT; 2. How IT has managed to take the manufacturing industry to the next level and how IT has provided many tools to enhance the capacity and efficiency of production, security, safety and quality in the industry and, 3.What are the future technologies which will boost the industry performance even more. In the end we discuss, what are the challenges before IT industry in implementation of new technologies and how those can be addressed to promote Agile Manufacturing.

Keywords: Agile Manufacturing, Information Technology, Manufacturing Industry, Automation

1. Introduction

The term Agile is generally used to refer enterprises that can adapt and respond to the turbulent environment changes and perform well [1]. And information technology has proved itself to be major contributor in this. Information technology (IT) is the application of computers and software to store, analyze, retrieve, transmit, & manipulate data or information, generally in the context of a business, industry or other enterprise. Information Technology is considered a subset of information and communications technology (ICT) [2]. The use and availability of information systems and technologies has grown almost to the point where it has become a commodity like labor. By 1991, U.S. companies spent more on information technology than any other form of investment; total spending on computers and related services got doubled from approximately $80 billion in 1984 to over $160 billion in 1998. Information systems include many different varieties of software platforms, frameworks, management systems and databases naming some of the few. These comprehend enterprise-wide systems designed to manage all major functions of the organization provided by companies such as SAP, PeopleSoft, JD Edwards and so on to more general purpose database products targeted towards specific uses such as the products offered by Oracle, Microsoft, and many others [3].

2. Manufacturing Industry before Information Technology

In the initial stages of manufacturing when computer was not present the data recording was in log books so it was very difficult to search for a particular entry and lot of effort to maintain those hard files. If a machine gets down, the error reporting was done by telegram and used to take many days for service engineer to come and repair it. Monitoring of inventory buildup and inventory decline was very cumbersome before introduction of barcode and RFID system as all the working and monitoring processes were manual.

I. Impact of Information Technology on Manufacturing

SAP was started in 1972 by five former IBM employees with a vision to create standard application software for real-time business processing and it made real time monitoring very easy with different access controls. Let’s take an example, suppose you work with Amex and Amex has various divisions, e.g. Risk Analysis, Accounts Payables, Sales & Marketing, CRM, etc. If there is an ERP (SAP), it will have the necessary ‘specific’ screens to capture the transactions happening in various departments and the access is also restricted. i.e. A CRM person does not have access to the Risk Analysis screen, etc. And when your MD or MIS team wants to review the performance at various levels, they can. Simply pull out various reports of the transactions happened in various functions.

Another tool is Computer systems use of barcode to keep track of products as they are manufactured and progress down the production line. Barcodes are used to track the progress of products as they are distributed to customers. As the product progresses down the production line the barcode is scanned repeatedly. NCR Corp. (which was then called National Cash Register Co) made one of the first UPC scanner in June 1974 and was installed at Marsh's supermarket in Troy, Ohio. On June 26, 1974, the first product with a bar code was scanned at a check-out counter. It was a 10-pack of Wrigley's Juicy Fruit chewing gum [4]. Introduction of Computer Aided Design made the designing process very comfortable

Now the design can be seen in three dimensions virtually and any changes made and their effect upon the whole design is visible to designer. Similarly Computer Aided Manufacturing (CAM) and Computer Aided Engineering (CAE) have made the manufacturing much more flexible and efficient. In the 1940s and 1950s, NC machines built, based on existing tools that were modified with motors that moved the controls to follow points fed into the system on punched tape. These early servomechanisms were rapidly augmented with analog and digital computers, creating the modern CNC machine tools that have revolutionized machining processes. In an enhanced version, if the available memory is short, the program is stored in a separate computer that has sufficient memory and is sent directly to the machine. This enhanced method is termed as Direct Numerical Control or Distributed Numerical Control (DNC) [5]. One more example at Thiokol, a major supplier for NASA’s Space Shuttle Program, collaborative practices between different workstations lead to a reduction of product development and lead time by 50% [6].

A. Cloud Computing and Agile Manufacturing

Cloud Computing is a technology of deploying a network of servers with centralized data storage and online access to computer services/resources. The idea of cloud computing in manufacturing has led to two categories of implementations [7].One concerns deploying manufacturing software on the Cloud and the other in which both material and non-material facilities are unified into manufacturing services in a way that permits full sharing of resources and capabilities. This may be the key enabling factor for agile manufacturing where it is important that the organization be able to respond quickly to customer requirements and market situations [8, 26].In fact a paradigm of Cloud Agile Manufacturing has been coined recently to take advantage of the benefits of Manufacturing Clouds [9].

In this work we would like to crystallize some of the aspects of Cloud Agile Manufacturing relate to aspects of efficient implementations through model development and simulations. Another concept that is attracting researchers is the cyber-physical production systems (CPPS), a concept that helps one realize agile cloud based cellular lean manufacturing by enabling communication between humans, machines and products. Intelligent manufacturing systems [10, 11, 12, 13] wireless communication, sensor networks and internet of things (IoT) made the development of high resolution manufacturing systems possible [14]. Finally Digital Factories [15, 16, 17] and Cloud computing led to cloud services to manufacturing.

B. 3D Printing/Rapid Prototyping

3D Printing/Rapid Prototyping is being assumed as a next revolution in Manufacturing and Industrial Engineering. In early 2014, Swedish supercar manufacturer Koenigsegg announced the One: 1 (Figure 1), a supercar that utilizes many components that were 3D printed [18]. Urbee is the name of the first car in the world car mounted using the technology 3D printing (its bodywork and car windows were "printed") [19]. In 2014, Local Motors debuted Strati (Figure 2), a functioning vehicle that was entirely 3D Printed using ABS plastic and carbon fiber, except the power train. In May 2015 Airbus announced that its new Airbus A350 XWB included over 1000 components manufactured by 3D printing. In 2015, a Royal Air Force Euro fighter Typhoon fighter jet flew with printed parts. The US Air Force has started working with 3D printers & the Israeli Air Force also purchased a 3D printer for printing spare parts. In 2017, GE Aviation revealed that it had used design for additive manufacturing to create a helicopter engine with 16 parts instead of 900, with great potential impact on reducing the complexity of supply chains [20].

Figure 1:Koenigsegg One car, the first homologated production car in the world

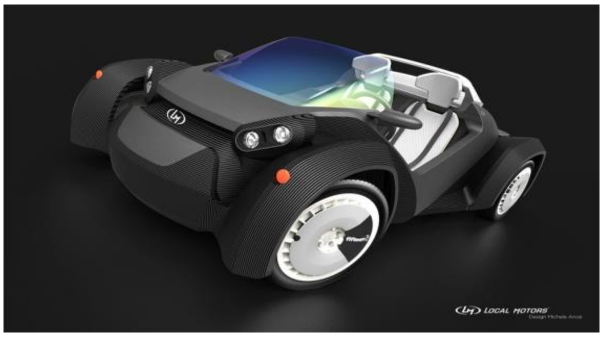


Figure2: Local Motors- Strati

C. Remote Support

Remote Support tool (like Team Viewer) for remotely accessing the machines from a distant location by the manufacturer enables the machine to be remotely repaired and hence saving time, reducing machine idle time and increases enterprise's performance which otherwise could have adversely affected. Introduction of E-commerce portals has opened new doors for supply chain management, it is now easier to work on JIT(Just in Time) manufacturing system because of better management of Supply Chain by E-commerce. Ecommerce giants like- Amazon, Alibaba, Flipkart, Ebay, etc., has proved it and making the changes continuously in the process. Moreover software frameworks like-wordpress, drupal, magenta etc., have enabled a single person to start one's own company with a very little programming knowledge.

II. Emerging IT tools- Artificial Intelligence, Machine Learning & Internet of Things (IoT) all leading to Automation

The Internet of Things (IoT) "connects people, data, things & processes in big networks thus creating vastamounts of information which, when analyzed and used intelligently, could create new efficiencies & innovations" [21]. The German conglomerate Siemens has been using neural networks to monitor its steel plants and improve efficiencies for decades. It was claimed by the company that this practical experience has given it a boost in developing AI for manufacturing and industrial applications. In addition, the company claims to have invested around $10 billion in US software companies (via acquisitions) over the past decade. In March of 2016 Siemens launched Mindsphere (in beta), which is a main competitor to General Electric’s Predix product. Mindsphere – that Siemens described as a smart cloud for industry – it allows machine manufacturers to monitor machine fleets for service purposes throughout the world. At the end of 2016 it also integrated IBM’s Watson Analytics into the tools offered by their service.

General Electric takes a holistic approach of tracking and processing everything in the manufacturing process to find possible issues before they emerge and to detect inefficiencies. GE’s first “Brilliant Factory” was built in the same year in Pune, India with a $200 million investment. GE claims it improved equipment effectiveness at this facility by 18 percent as it is powered by Predix (Figure 3), their industrial internet of things (IOT) platform.

IT giant TCS has built “The TCS Digital Store TM” that contains more than 150 solutions, including TCS Plant Operations for real time analytics in a manufacturing plant, Environmental Health and Safety Analytics for industrial facilities, Plant Equipment Prognostic Maintenance, and Engine Telematics for tracking and logistics. More than 50 of these solutions are built on GE’s IoT- Predix [22].

Japanese company-Fanuc, a leader in industrial robotics, recently made a strong push for greater connectivity and AI usage within their equipment. In early 2016 it announced collaboration with Cisco and Rockwell Automation to develop and deploy FIELD (FANUC Intelligent Edge Link and Drive). It is described as an industrial internet of things platform for manufacturing. Just a few months later Fanuc partnered with NVIDIA to use their AI chips for their “the factories of the future”. KUKA claims their LBR iiwa “is the world’s first series-produced sensitive, and therefore HRC-compatible, robot.” Its use of intelligent control technology and high-performance sensors means it can work right beside a human without the risk of accidentally crushing a person [23].

Another example of automation, the software tool 'OptiWo' can depict global production networks in a holistic way and helps to optimize their complete design and setup [24].

III. Challenges for IT in Implementation of technology

A. Cloud Computing

Cloud Computing One of the thorniest issues is who owns the data and how the provider is supposed to keep it which is an important concern in law enforcement and litigation-related requests, notes "Forbes" magazine. And a Debate also persists that whether companies are letting their IT staff manage the data or are dealing with a cloud vendor who is specially certified in security protocols affecting the medium cyber security.

B. Cyber Security

One important concern is maintaining the security of their clients because there are unknown bugs and loopholes present in the system which no one is aware of and when they are known by some black hat person, it could be exploited and used in malicious way. Recently a bug in Wi-Fi called KRACK (Key Reinstallation Attack) is a serious loophole and it has no solution and is an open threat to the world. There are many cases of virus and malware attacks like Ransom ware asking for money to unlock the files. Open SSL encryption was considered to be safe nut it got Heart bleed vulnerability. So it is very difficult to maintain the client’s privacy and data safe in this internet connected world which is a great challenge for these IT companies.

C. Big Data Management

Because today the world is dealing with a lot of data and Internet of Things which generates a lot of data and to process in real time is a big

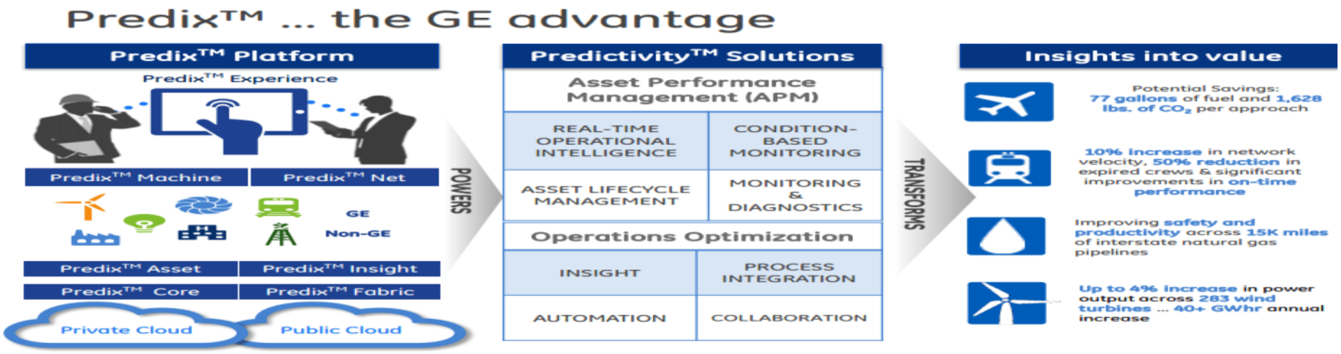


Figure 3:Predix, an IOT platform by General Electric

challenge. New technology like Hadoop has solved this problem.

D. Skilled Labour and Talent Retention

Skilled Labor and Talent Retention It is difficult for an industry to retain their top talents because their rivals are ready to pay them more to get that talent and also due to emergence of new technologies every year, there is a huge demand for skilled labor.

IV. Digital Twin and Industry 4.0

IT activity includes:

SaaS- Software as a Service - AI- Artificial Intelligence (adoption for efficient manufacturing).

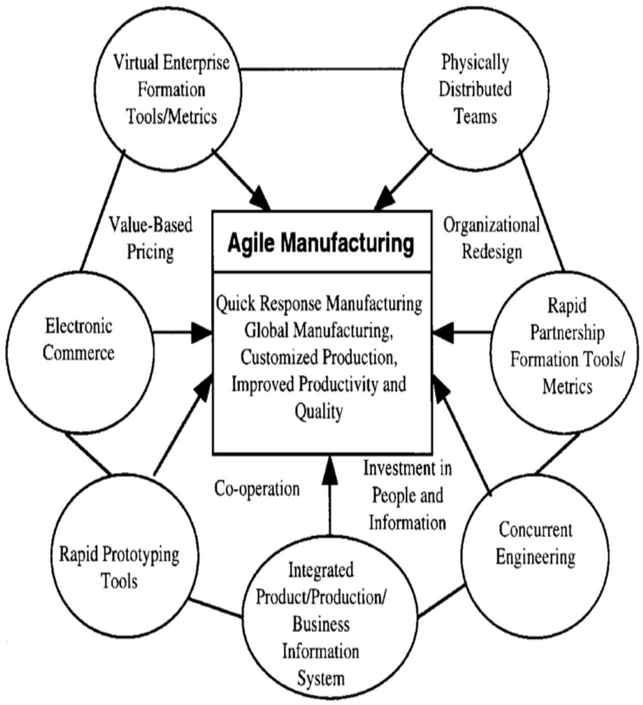
IaaS- Infrastructure as a service - use of Cloud and creation of real time Database, Data Center/Cloud outsourcing and their security.

Covid-19 causes reorganization of IT services for agile manufacturing, condition based maintenance and quality monitoring. Mobile application for Agile manufacturing control and monitoring.

Respond to continuously changing situations Remote working or Working from home for agile manufacturing.

3. Conclusion

Information Technology has transformed the way, the manufacturing used to work and is continuously improving connectivity, data sharing capabilities, supply chain management, production activities monitoring in real time intelligently. In future it will be possible to store data in such a global cloud system where it can be recalled fast and independently from any geographic location. Though there are some challenges for this industry in implementation for their technologies but if dealt in an agile manner those can be easily answered.



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Biography

Vipin Mittal is an M.Tech (Engineering Systems) student in Dayalbagh Educational Institute, Dayalbagh, Agra. He earned B.Tech in Mechanical Engineering from GLA Institute of Technology & Management, Mathura. He has published a Research paper in "Applied Mechanics & Materials Journal." His interests include computer programming, manufacturing, optimization , Internal Combustion Engines etc.

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Prof. Subra Ganesan is a Professor in Engineering, Oakland University with more than 30 years of experience in teaching, research and industry. He is a consultant to Texas Instruments Inc., 1988-89, 1991, Motorola Inc., 1989, Compression Lab, California, 1988, Vickers, Inc., 1990,Chrysler 1994-98, 2005, 2006, General Motors: 1996-97. His research interests are Real time Digital Signal Processor systems, Parallel computerarchitecture, Sensor network and applications, Cloud based Agile Manufacturing. His recent Awards include: Jan 25 2015- Hind Rattan award from NRI India, 2014- Best professor of the year 2014 from Bangkok. ; 2014-May—Fellow ISPE-International Society of Productivity Enhancement; 2014- May—Best Service Award ISPE.; 2012 December received "Life Time Achievement award" for illustrious career in teaching, research, and administration and contribution to the fields of engineering, conferred by ISAM, USA, 2012, Withrow Wilson Distinguished Speaker SAE; Life Time achievement award,for teaching, research and contributions to engineering, ISAM, USA, December 2012; Fellow ISPE 2014; 1999 Outstanding Teacher Award- ASEE- North Central Section; Naim Kheir Teaching excellence award Oakland University, 1999; Best Paper award- First Prize- IEEE Electro Information Technology conference, June2001. Best Paper award IJAM 2014 journal, He published around 70 Journal papers, 12 books and 190 papers in refereed conference proceedings.

Prof. K. Hans Raj is a Professor in Mechanical Engineering Department with more than 31 years of experience in teaching and research. He teaches Finite Element Analysis, Artificial Intelligence, Engineering Mechanics, Soft Computing Techniques and Computer Aided Design. His research interests include Intelligent and Agile Manufacturing, Metal Forming Process Modeling and Optimization, Soft Computing Applications in Manufacturing and Evolutionary Optimization. He was conferred more than 50 recognitions and awards by National and International organizations including Lifetime Achievement Award by ISPE and ISAM and Vikram Award 2017 by System Society of India(SSI) constituted in the memory of Late Hon. Vikram Sarabhai. He has completed several R&D projects (more than 17) and has provided consultancy to a number of government agencies including ADRDE and National/International companies. He has wide recognition in various universities around the world and has visited more than 17 universities of International repute including University of Maryland, USA, University of North Carolina, USA, MIT, Boston, Western Michigan University, RPI, Troy, USA. As a visiting scientist he undertook collaborative research work at University of Kiel, Germany, CEMEF Laboratory, France. He has hosted several National/International conferences and has chaired several sessions in a number of National/International conferences. Some of his research contributions include Design of an Aerostat Winching and Mooring System for ADRDE (DRDO), Detailed Finite Element Analysis of Air Inflatable Hemispherical Dome for ADRDE, Detailed Finite Element Analysis of Hot Extrusion of a Transmission Shaft, Hot Closed Die Forging of a Piston and Hot Powder Forming of a Gear, Application of Artificial Neural Networks to the Modeling of Orthogonal Cutting, Upsetting and Extrusion Processes, Development of Group Technology Cell Formation with Similarity Co-efficient, ART2, Competitive Nets and Kohonen Map Neural Network Paradigms, Application of the same to Intelligent Manufacturing systems and Socio-economic Systems, and Indigenous Development of Friction Stir Welding Machine. He is an eminent researcher and has authored more than 146 research papers, 5 technical reports/ books/ monographs and a patent. He is the Editor of International Journal of Agile Manufacturing (IJAM).

OBITUARY FOR DR. LIONEL FOURMENT

Dr. Lionel Fourment, age 56 has left this world on November30, 2019 on account of Cancer at France. He was survived by his wife Dr. (Mrs.) Christiane and three children Felix, Colin and Luce.

Lionel was born on 3rdNovember, 1963. He obtained his engineering degree in 1986 from E.N.S. de Techniques Avancées, Paris, France, Master's in Materials and Metallurgy in 1988 from Mines Paris, ParisTech Sophia Antipolis, France. He worked for his Ph.D. in Materials Sciences and Engineering 1987-1992 under the supervision of Prof. Jean-Loup Chenot at Mines Paris, ParisTech Sophia Antipolis, France. He worked as Assistant Head CEMEF and contributed immensely through his group of Advance Computing in Material Forming. He had a great passion for teaching and research and mentored a number of students at Masters and PhD level and published very high quality research papers in peer reviewed journals.

His research areas included: Optimization Methods, Optimization Algorithms, Sensitivity Analysis, Error Estimation, Adaptive Meshing, Adaptive Re-meshing, Contact Formulations and Algorithms, Iterative Solvers, Multi-Grid algorithms, Parallel Solvers, Arbitrary Lagrangian Eulerian formulations, Incompressible and Compressible Flows, Mixed Formulations, and Complex Couplings. He had made significant contributions to the application of numerical techniques to the fields of Forging, Forging Optimization, Metal Powder Forming, Thixoforming, Super-Plastic Forming, Ring Rolling, Glass Beading, Tube Bending, Rolling, Machining, High Speed Processes, and Friction Stir Welding.

He acted as a reviewer for International Journal of Numerical Methods in Engineering, Computer Methods in Applied Mechanics and Engineering, Revue Européenne de Mécanique, Finite Elements in Analysis and Design, Acta Materialia, International Journal of Damage Mechanics, International Journal of Forming Processes, International Journal of Solid and Structures, Steel Research International. He was a Member of the board of the ESAFORM (European Scientific Association for Material Forming) association. Member of the scientific committee of NUMIFORM 2010, June 13-17, 2010, Pohang, Korea, Member of the scientific committee of the 13th ESAFORM Conference on Material Forming, Brescia (Italy), 7-9 April 2010, Member of the Jury for the ESAFORM Prizes, Member of the scientific committee of the 12th ESAFORM Conference on Material Forming, Enschede, 27-29 April

2009, Member of the Jury for the ESAFORM Prizes, Member of the scientific committee of the 11th ESAFORM Conference on Material Forming, Lyon, 23-25 April 2008, Member of the scientific committee of the Journeé de Mécanique des Structures organized by and at Faculté des Sciences et Techniques de Settat on 26 November 2008, Member of the scientific committee of the ESAFORM association since June 2006. He was conferred with Fellow of International Society of Agile Manufacturing (FISAM) during NUMIFORM 2016.

Dr. Lionel Fourment was greatly impressed by Most Revered Dr. M.B. Lal Sahab and Most Revered Prof. P.S. Satsangi Sahab, the spiritual leaders of Radhasoami faith at Dayalbagh, Agra and visited Dayalbagh a number of times. His last visit to Dayalbagh with his family was in the year 2018. He was the connecting link between the two great institutions, CEMEF and Dayalbagh Educational Institute (DEI). He was a Buddhist by faith. Dr. Lionel Fourment has kindly mentored the author along with Prof. J.L. Chenot for his doctoral dissertation. He was a great family friend of the author. His research acumen, his kindness and compassion for all his family members, friends, colleagues and students is extraordinary.

We at DEI, ISAM and ISPE join all his family members, relatives and friends and pray to the Merciful God to bless his soul and bestow courage to his family to bear this great loss.

K. Hans Raj

Professor and Head Mechanical Engineering

Dayalbagh Educational Institute, Agra, India.

Chief Editor, IJAMS and Chairman, ISAM

IJAMS

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