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ScienceDirect

Procedia CIRP 54 (2016) 181 – 185

www.elsevier.com/locate/procedia

6th CLF - 6th CIRP Conference on Learning Factories

Industrialization of metal powder bed fusion through machine shop networking

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Abstract

Even though journalists write about the 4th industrial revolution, the metal additive manufacturing (AM) machines are still "that awkward machine in the corner". However, the research community and the European Commission have seen that hybrid solutions are necessary to improve the competitive factor of additive machines, making them an integrated supplementary part of the production plant, as other manufacturing processes are today. Hence, a discussion is raised on changing the way additive machines are operated. The paper discusses new planning systems and support systems for reliable operation of AM processes.

Peer-review under responsibility of the scientific committee of the 6th CIRP Conference on Learning Factories
Keywords: Manufacturing cell, Additive manufacturing, Machine networks, Powder bed fusion, Hybrid production

1. Introduction

The metal additive manufacturing (AM) technology can produce geometries that is impossible to create using traditional production technologies[1–3], while at the same time achieving good material properties with high performance metals [4,5]. However, for massive parts AM is a slow manufacturing process that usually have a roughness exceeding a *Ra* value of $10\,\mu$m. The geometrical accuracy is poorer than many traditional methods, since inherent stress will cause the part to deform during production and heat treatment. Therefore, an additive manufactured part is often machined, grinded and/or polished to get the part within its tolerances. Hence, machining allowance is added to the near net shape additive part. A company producing additive parts in metal, therefore, needs to have subtractive production machines for finishing operations. This is not in line with the common journalistic view of the simple one-operation AM machine, rather the AM machines are supplementary to the rest of the workshop, as the AM machines are not the solution to all production needs.

1.1. The supplementary additive process

The idea of hybrid systems are not new, as there are several hybrid solutions available. Already in late 2011 the company Matsuura displayed a CNC milling and laser powder bed fusion hybrid machine. Such a process was also presented in 2014 by the American machine builder Sodick. These machines deliver a hybrid manufacturing solution in a single machine unit, where the perimeter of one to four AM applied layers are milled before the application of the next layer, producing a smooth part with high dimensional accuracy. However, this solution still needs to start with a machined build platform, i.e. platform that provides the surface upon which the build is started and supported during the build process. This leads to another machining operation, as the platform has to be removed after the build. The layerwise milling is an additional operation which furthermore slows down the AM process sequence, and the restriction to 3-axis milling limits the possibilities to use the milling operation in the most efficient way. Chips blended into the powder bulk and magnetism are other major concerns regarding this process, as well as the deformation seen from the inherent internal stress that is added to the component during the build.

Deposition based hybrid manufacturing machines have been developed for many years [6,7]. In 2013 Hybrid Manufacturing Technologies displayed their AMBIT™ deposition head, which is a deposition head that could be retrofitted into virtually any CNC machine. Shortly thereafter DMG Mori Seiki showed a large deposition and milling hybrid machine. This type of hybrid machines became popular in 2014, when Mazak, Hurco and Hermle announced their plans for additive-milling mixed machines [8]. However, all these solutions are based

Peer-review under responsibility of the scientific committee of the 6th CIRP Conference on Learning Factories
doi:10.1016/j.procir.2016.05.089

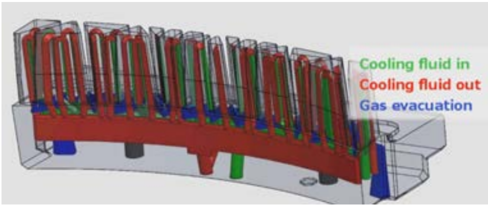

Fig. 1. A hybrid produced case study from the EU-project IC2

on the relatively coarse deposition method, often called Laser Cladding. In these hybrid machines milling and AM can not be done simultaneously, so there is always one process waiting for the other. Furthermore, between AM and milling there is also a cooling phase where the machine is waiting for the component to cool down. Hence, having separate machines instead of the 2-in-1 solution would be beneficial for the availability of each process.

Concept Laser, one of the major metal powder bed machine builders, have presented the idea of a bigger automated hybrid system. The company plan to release their first factory system at the end of 2016 [9]. The system will mainly focus on additive production with separate powder handling and removal stations. Furthermore, it will have a post-processing section, where the parts are machined, heat treated and cut off from its build plate. The focus is therefore on complete additive builds, with simplified post-processing steps.

1.2. Cell structures

The focus on automated cell structures are still not much discussed by the machine builders. However, a different approach to hybrid manufacturing started in 2009 at the Norwegian University of Science and Technology and SINTEF in Trondheim, Norway [10]. With this approach a powder bed AM machine for metallic materials is integrated with a 5-axis milling center into a hybrid manufacturing cell. Physical integration is done by a pallet system, while the machines are connected to a local network for information exchange, e.g. part position coordinates and part name. The intention of this approach was to achieve coordinated functionality while the integrity of each process was maintained to the highest degree possible [11].

This development was a part of the European project FP7 IC2. A case study on an injection molding tool insert revealed more than 50% decrease in mold cooling time, and much less wear on the mold. This extreme decrease in wear was seen from the change of material, better venting and much better cooling. The vents where built additive and the cooling channels where comprised of many parallel conformal cooling channels, as seen in Figure 1.

A recent contribution to the development of hybrid manufacturing is the MetalFAB1^{TM} , shown by Additive Industries at the FormNext exhibition in 2015. It is a modular machine that is supposed to integrate many different process steps, like powder bed fusion, heat treatment, powder removal, storage and probably some subtractive modules. These are all connected by a supervising control system and a linear robotic unit. A pallet system is used to achieve consistent part positioning in the machines. This modular system has the potential to be a major success, if implemented correctly. However, from the information available at this time, it seems that the system will focus on building a part completely in the additive machine, just like the Concept Laser factory system.

As stated, AM is slow and rough, which is why it is usually not the preferred method when compared to subtractive processes. On the other hand, the unique possibility to produce geometrical complexity is important for some products. Hence, there is a need for AM, but there is also a cost-driven need to reduce the use of AM. This is why hybrid systems has been developed, integrating very different production machines together, to improve the speed and performance [12].

2. The hybrid modular manufacturing system

The idea of the hybrid modular system is to link together several production machines in a workshop, while maintaining the integrity of each individual machine. There has to be a network-based connection, as the machines need to exchange information, e.g. part location, deviations, identification and production files. As a result, a single setup of the crude base section on a pallet system will reduce the setup time, and the accuracy of the setup will be reflected by the accuracy of the pallet system. 3D-scanning or coordinate measuring machines (CMMs) will inspect the parts between the process steps to identify problems and to learn about the different failure modes. Figure 2 displays an example of a communication flow in an automated system, where part positions, deviations, identification, machine codes and other relevant information is communicated through a common system router. Some of the feedback is also sent to a learning database, which is used for learning the process deviations and failure modes.

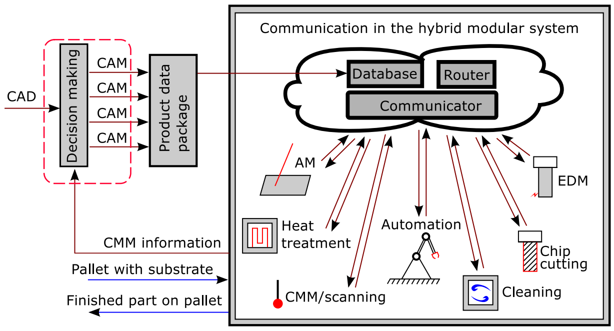

Fig. 2. The hybrid modular manufacturing system

The hybrid process starts when a CAD-model is loaded into a hybrid manufacturing toolbox. This toolbox analyzes the geometry and gives feedback to the engineer on which production method that is recommended in different sections of the part. The feedback could give indications of design modifications that could make the manufacturing process less resource demanding. The feedback is based on knowledge of each production process and a knowledge database which is developed over time. The option at this point is to redesign the part, or to section the part as the toolbox recommends. Each section is then presented in a CAM-software for each of the process steps, where the tool paths are programmed. The toolbox then produces a product data package that will hold the production files and identification. This package is updated with positioning through a 3D-scan, or for more accuracy, a CMM.