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Metal cutting and additive manufacturing as an integral stages of metals hybrid manufacturing in Industry 4.0

Obróbka skrawaniem oraz techniki przyrostowe jako integralne etapy procesu wytwarzania hybrydowego z metali w Przemyśle 4.0

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This paper describes the role of metal cutting process as integral part of manufacturing with application of MAM (Metal Additive Manufacturing) techniques. Additive Manufacturing is written explicit as main feature included in Industry 4.0 cycle. AM techniques lead to hybrid manufacturing techniques as well. This paper points that AM almost always is accompanied by supplementary conventional machining.

KEYWORDS: additive manufacturing, post-processing, Industry 4.0, hybrid manufacturing

Industry 4.0

The fourth industrial revolution, called Industry 4.0, aims to increase economic competitiveness by integrating modern production techniques with new information technologies [1]. Its two basic areas are virtual and physical - together they are a cyberphysical system. The virtual environment includes Internet of Things (IoT), cloud computing and Big Data, while in the physical environment there are autonomous robots and additive manufacturing (AM) (fig. 1) [2].

Industry 4.0 is based on the paradigm of mass, personalized production, so it is necessary to develop non-traditional methods of manufacturing products that comply with individual customer requirements. Therefore, AM can become a key technology for manufacturing non-standard products - objects with advanced attributes (new shapes, new materials) [1]. Due to the greater possibilities of manufacturing products with complex geometry, additive manufacturing is currently used in various branches of industry, such as aviation and biomedicine [3]. It is a rapidly growing technology for creating accurate and complex objects. In the near future, it can replace conventional production techniques.

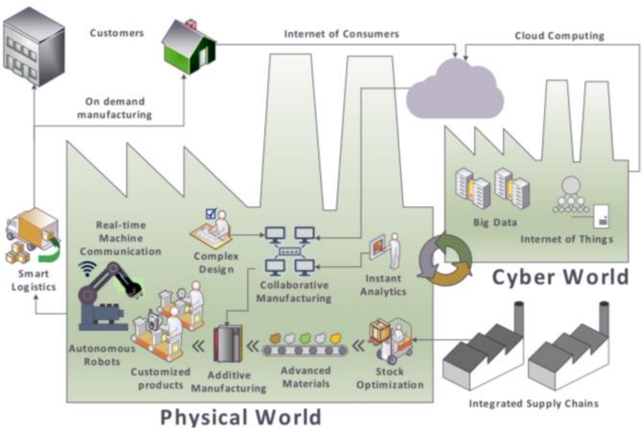

Fig. 1. Scheme of intelligent factories divided into areas and main issues [1]

According to the Wohlers report from 2017 [4], with the development of technology in the coming years, the share of 3D printing in the production of parts and even finished products is expected to grow. The report points to scenarios (based on investments in additive techniques), according to which as early as in 2040 or at the latest in 2060, as much as 50% of global production will be created on additive manufacturing equipment.

Selective melting of metal powders

Additive manufacturing techniques use a wide range of materials - from liquid crystal polymer resins, thermoplastics to metals. The latter offer the greatest opportunities in the context of mass production [1]. Metal additive manufacturing (MAM) is already the most frequently chosen technique in industry [5], which results from the wide use of metal elements in almost all engineering areas [1]. Two methods using metal powders are the most widespread among MAM techniques:

- selective laser melting of metal powders and their alloys (selective laser melting/direct laser metal sintering, SLM/DLMS), implemented in the automotive industry [6];
- electron beam melting (EBM).

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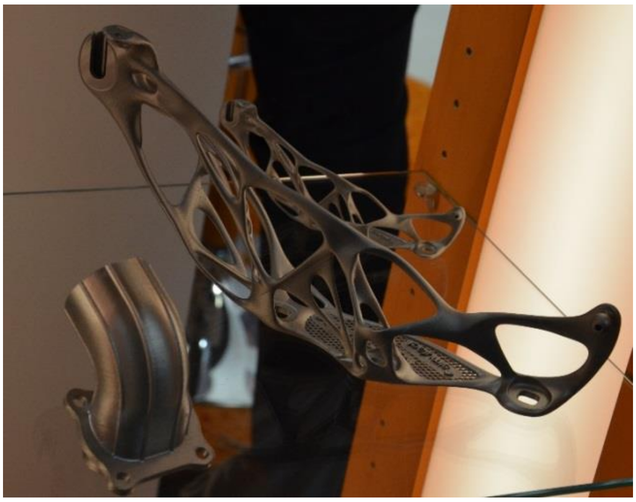

Fig. 2. Automotive components manufactured using DLMS/SLM topology optimization

Fig. 3. Aircraft elements (a) and car parts (b) with precisely machined flanges

The SLM/DLMS methods allow the production of metal elements with virtually any complex geometry (fig. 2 and fig. 3), on a unit or series scale.

An integral process of additive manufacturing is the removal of manufactured elements from work platforms. The most often used for this method are electro-discharge machining. As a rule, machining of the right part is also necessary, aimed at correcting the inaccuracy of additive methods [7]. This stage is treated as finishing (postprocessing), especially elements of cooperating parts. Fig. 3 presents the elements that require finishing to correct the accuracy of mounting holes (fig. 3a) or holes in the nozzles (fig. 3b).

It is worth noting that under Industry 4.0, hybrid production is planned that will combine various additive techniques or lead to different combinations of production processes, going beyond the conventional MAM processes, to produce better products, with higher surface quality, greater fatigue strength, etc. [1]. Hybrid machining processes, especially combinations of additive and substractive machining, require an individual approach to part modeling already at the stage of 3D design in CAD programs. Since main problems are just homing and fastening elements (see item in fig. 4a), it is necessary to predict the treatment technology of the cavity. Special machining bases are used here, which are then removed [8]. This approach to hybrid machining not only provides the correct fastening, but also, depending on the functions and construction bases, it enables to achieve the assumed dimensional and dimensional accuracy. In special cases, it is possible to use - as the basis elements - production plates, which during the machining processes act as pallets. Of course, the possibility of processing the lower fragments is then limited. It should be added that manufacturers of incremental processing equipment (e.g. SLM Solutions) are currently investing in software that allows the integration of machining processes in integrated CAD/CAM systems, as has been the case with substractive machining processes for years.

MAM methods with the use of metal powders are used on an industrial scale, mainly where the surfaces are curved or where the channels are to be, for example, conformal (as in aircraft constructions). Such elements are shown in fig. 3. The upper element (fig. 3a), with precisely machined flanges, is the fuel joint of the Airbus A 350. The lower element (fig. 3b) requires precise homing and performing the substractive treatment. The obtained machining accuracy, treated as postprocessing, depends on its preparation at the design stage of AM parts and processes. This was confirmed by Flynn et al. Who in their work [9] noted that the synergistic combination of additive manufacturing processes and substractive processing within a single workstation allows to take advantage of each of these processes and facilitates the production of high-aspect elements with the desired geometrical accuracy and surface characteristics. Similarly, Manogharan et al. [8] emphasized that it is possible to improve the efficiency of the process through a hybrid process consisting of EBM and CNC rapid machining.

Hybrid machining on machine tools

A certain reversal of the problem is the use of a head using LMD/DMD technology (laser metal deposition/direct metal deposition) as one of the tools used on metal cutting machines. An integral part of the machining process is additive production, preceding machining (postprocessing). Such hybrid machining can be used as a production process or a process of part regeneration or error correction at a construction or technological level. CAD/CAM software vendors commercially offer software tools for the design of technological processes using this type of processing, called hybrid processing (e.g. Siemens NX).

Methods alternative to MAM of metal powders

Methods using metal powders are characterized by the complexity of the process and the high costs of equipment and material, and - due to the strong carcinogenic effect of metal powders - require a special, very expensive infrastructure. This applies not only to the process itself, but also to pre- and postprocessing, i.e. preparation and drying of the material and subsequent processing. In each of these processes, it is necessary to comply with strict safety regulations (including regulations regarding the risk of ignition, inclusive). So there is a trend to develop alternative methods. Since it is not true that - as originally announced -

the MAM methods will completely replace the classical machining, there are methods in which machining is part of the technological process of shaping parts.

Innovative methods with high volumetric efficiency are, among others, WAAM/SMD (wire + arc additive manufacturing/shaped metal deposition) and commercial AMLTEC™ method (additive metal layering technologies), reserved for AML Technologies in the USA, which are based on multi-layer, precisely controlled arc welding [10-12]. These methods have recently been implemented in the aerospace industry, because they allow the formation of all weldable metals and the production of very large components [10].

Fig. 4 presents the elements manufactured by the WAAM method using pre-machined base parts. In this method, machining is a shaping process as in the case of semi-finished products made by plastic forming or foundry methods. However, this is also the MAM method, characterized by a high degree of freedom of shaping and volumetric efficiency (for the element in fig. 4a - 280 cm^3/h).

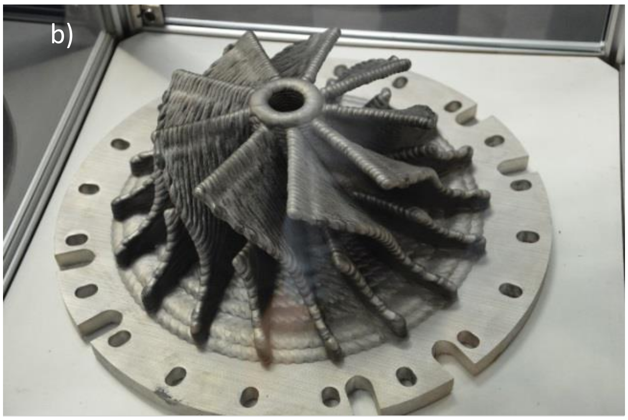

Fig. 4. Examples of components made by the WAAM method: a) propeller produced directly on the finished cylindrical blank, b) turbine designed for comprehensive machining in five axes

Fig. 5. Exemplary demonstration element made by MFDM

The method of increasing popularity is also MFDM (metal fused deposition modeling), referring to the well-known FDM method, that is applying layer by layer, which, goes into a solid phase after postprocessing. In the case of the production of machine parts, this method requires the use of machining processes. It is used for the production of small-size components. It belongs to methods that do not require industrial infrastructure (desktop devices). An exemplary element produced by this method is shown in fig. 5.

Conclusions

Additive methods in combination with conventional methods create the possibility of producing both personalized elements (e.g. implants or orthopedic aids) as well as entire series in production conditions. Additive manufacturing processes become stages of typical technological processes and start to be supported by computer-aided manufacturing (CAM) systems as typical technological processes combined with substractive treatment processes. Similarly, they begin to be elements of PPC (production planning and control) and ERP (enterprise resource planning) systems. Soon, combining the additive and substractive machining will cease to be a hybrid treatment and in the era of the fourth industrial revolution will become a classic manufacturing.

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