ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering
Tome XV [2017] – Fascicule 2 [May]

ISSN: 1584-2665 [print; online]
ISSN: 1584-2673 [CD-Rom; online]
a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

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TECHNOLOGY-BASED ASSISTANCE SYSTEM OF ADDITIVE PROCESS CHAINS FOR PROTOTYPE MANUFACTURING (TAGAP)

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Abstract: The future of manufacturing is characterized by an increasing customization of the products. With intelligent decision-making processes mostly SMEs will be controlled and optimized in near real time. The additive manufacturing processes allow the individualization (industry 4.0) with high flexibility. Complex products can be manufactured in layers from CAD data. The additive manufacturing methods are ideally suited for integration into a networked service and manufacturing. The applications of additive manufacturing processes have to be developed and optimized technologically as well as economically. The development of TAGAP should allow the user an optimal generation technological process chains of additive manufacturing.
Keywords: rapid prototyping, assistance system, technology optimization, additive process chains

1. INTRODUCTION

The additive manufacturing processes are an important production-orientated contribution to supporting for customization of products. They must be integrated as a manufacturing option amplified in the activities of designers and technologists. They offer a unique opportunity from CAD datasets to manufacture highly complex products in layers reproducibly. Due to their information technology and manufacturing flexibility, they are excellently suited for integration into a networked service and manufacturing [1, 2].

The additive manufacturing processes have become known under the name of "rapid prototyping" and "3D printing". Unlike traditional machining processes that remove material to create a part, these manufacturing techniques use an additive process where parts are created layer by layer, in different shapes and sizes. Major advantages of additive manufacturing processes are in almost trouble-free processing and creating of geometrically complex parts and in customized manufacturing in small quantities. In addition, the product development and planning times can be significantly reduced in the fabrication of prototypes. Thus, the components can be provided promptly to the market.

In this context, a great demand of a technological assistant for optimal selection of additive fabrication process was observed by the industry. The required secondary processes and follow-up technologies should be considered in connection with the additive fabrication, because they significantly influence the time and costs. The service providers and prototype manufacturers also require the integration of an assistance system in the existing CAD and ERP systems. This is a necessary requirement for a user-friendly application of the assistance system TAGAP.

2. PROCESS CHAINS OF ADDITIVE TECHNOLOGIES

The industrial application of additive manufacturing processes has increased in recent years greatly [2,3,4]. The following types of components are distinguished [5]:

- Rapid prototyping = additive fabrication of parts with limited functionality
- Rapid manufacturing = additive fabrication of end products
- Rapid tooling = the use of additive technologies and processes to fabricate tools and molds

In Table 1, the additive manufacturing processes used in the industry are presented at a glance. They are basis for decision making of the assistance system TAGAP.

Table 1 – Overview of selected additive techniques (referring to VDI-guideline 3404 [6])

	Fabrication process	Source material	Binding mechanism	Secondary process
Stereolithography (SL)	additive technique in which photopolymer resins (polymers with photo activators) selectively cure, or solidify, when exposed to a laser beam	liquid or paste: synthetic resin with or without filler	chemical	cleaning post-curing in UV oven
Laser Sintering (LS)	additive technique in which powdered material is selectively melted, or sintered, when exposed to a laser beam	powder: high polymers, metal alloys, ceramics with or without fillers and binders	thermal	compressed air cleaning
Laser melting (SLM, EBM)	additive fabrication process wich utilises lasers or electron beams to selectively melt powdered materials, which then fuse during solidification	powder: metal alloys	thermal	post-processing to improve the surface finish: microblasting laser-assisted material removal laser remelting PVD coating
Fused layer modelling/ manufacturing (FLM)	additive technique in which a thermoplastic material is melted and selectively deposited through a heated nozzle or print head; the material hardens immediately after deposition. Each sucessive layer may be milled or not, depending on the technology	filament: one or two different high polymers (component material, support material) with or without filler	thermal	cleaning
3D Printing (3DP)	additive technique in which an adhesive is deposited dot by dot onto a powder bed, causing the powder to bond where the adhesive is deposited	powder: powder mixes (polymers, ceramics, etc.) liquid: adhesive	thermal and/or chemical	compressed air cleaning impregnation with liquid hot wax or infiltration with epoxy resin or adhesive; necessary to increase the mechanical resistance; sintering (ceramics)

Industrial applications of additive manufacturing methods are mainly the following industries:

- automotive engineering
- aerospace engineering
- tool and mold production
- mechanical and plant engineering
- medical engineering
- sports engineering

Depending on the chosen manufacturing principle and the prototype application secondary processes and follow-up technologies may be necessary after the fabrication process. The totality of the necessary steps is referred to as rapid prototyping process chain [6] (see Figure 1). The additive fabrication processes are divided into direct and indirect processes. Direct processes are able to produce the component with all of required properties. Thus, they are the ideal case in the prototype manufacturing in terms of material savings and manufacturing costs. With indirect processes, a master form is produced additively for selected follow-up technologies (e.g. investment casting). Here also savings in terms of materials and manufacturing costs can be achieved. All of process data of additive fabrication processes must be fully considered in the assistance system TAGAP. Furthermore, the information technology process steps (e.g. CAD model, CAD- and ERP-

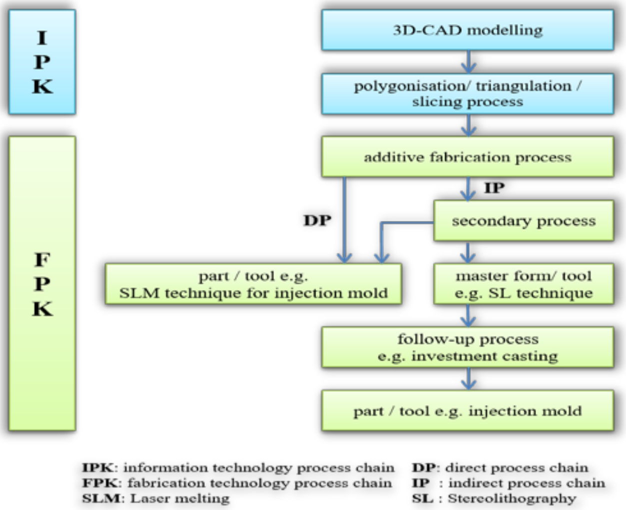

Figure 1 – Process chains of additive technologies (rapid prototyping)

interfaces) and fabrication technology process steps to be considered (e.g. direct manufacturing of metallic tools using laser sintering).

3. STRUCTURE OF TECHNOLOGY-BASED ASSISTANCE SYSTEM TAGAP

The functionalities of the technology-based assistance system TAGAP for optimal selection of additive fabrication methods in combination with follow-up processes can be realized by a two-stage decision methodology (see Figures 2). It is divided into the steps of "technology-strategy-determining" and "generation and evaluation of process chains" [7].

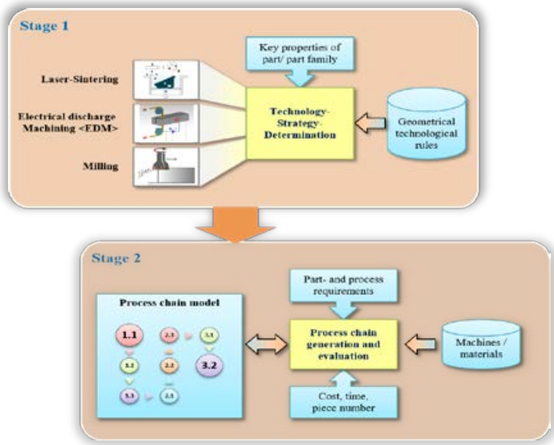

Figure 2 – Two-stage decision method of TAGAP

3.1 Technology-Strategy-Determination

With stage 1 "technology-strategy-determining" (see Figure 3) the suitability and possible applications of additive fabrication processes are analyzed for the manufacturing task. The technology strategy is decided on the basis of key criteria (e.g. part complexity, material) and rule-based knowledge as well as experience. The objective is to make early decisions on the applications of additive manufacturing processes as distinct from the conventional manufacturing processes. The main aims of technology strategy determination are:

- Rapid and with low expenditure technological decision with key criteria
- Comprehensible demarcation of the applications of additive and conventional production methods for the present manufacturing task
- Mapping of technological knowledge and experience in the rule base for the industrial important additive fabrication processes (see Table 1) in combination with follow-up processes
- Considering the combination of additive manufacturing processes with follow-up processes, such as plastic casting method. This technological process chains offer great potential for producing plastic components.
- Direct manufacturing metallic tools by laser sintering or laser melting for plastic injection molding process
- Key criteria for selecting the technology strategy are mainly:
  - component types (concept prototype, functional prototype, technical prototype)
  - material (plastic, metal)
  - geometrical complexity
  - dimension
  - dimension accuracy
  - surface quality
  - piece number

3.2. Generation and evaluation of process chains

The detailed generation and evaluation of process chains is carried out in stage 2 (see Figure 4) after selecting the technology strategies.

Basis of the generation and evaluation of process chains are the illustrated process sections (shown in figure 1) of additive techniques considering of secondary and follow-up processes.

The possible additive process chains are generated based on the design requirements, the defined features and technological rules. It is divided, if the prototypes are manufactured directly or indirectly. The manufacturing equipment resources are allocated the generated process chains automatically. Subsequently, the manufacturing variants are evaluated and optimized according to time, cost, quality and quantity. On this basis, the optimal additive process chain is selected.

4. MANUFACTURING VARIANTS OF INJECTION MOLD

Different manufacturing options are shown in Figure 5 using the example of an injection mold. These are the result of technology-strategy-determining by means of defined key criteria (decision stage 1). The injection mold can be manufactured both conventionally by milling, EDM and by additive manufacturing processes of laser sintering or laser melting.

The evaluation of the process chains (decision stage 2) shows that the additive fabrication of prototypes in manufacturing times and manufacturing costs is advantageous.

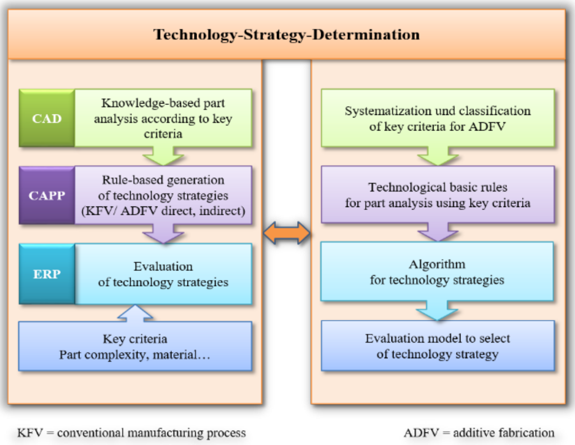

Figure 3 – Method of Technology-Strategy-Determination (Stage 1)

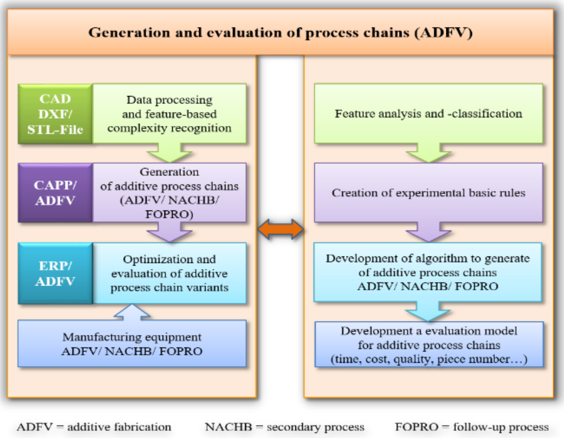

Figure 4 – Method of generation and evaluation of process chains (Stage 2)

Future task of the research project is the investigation of piece number influence and component quality for direct and indirect process chains.

5. CONCLUSION

The following objectives are achieved with the development of the assistance system TAGAP:

- Comprehensible technological decision for production of prototypes by means of additive and / or conventional manufacturing methods
- Evaluated applications of direct and indirect process chains of additive manufacturing processes

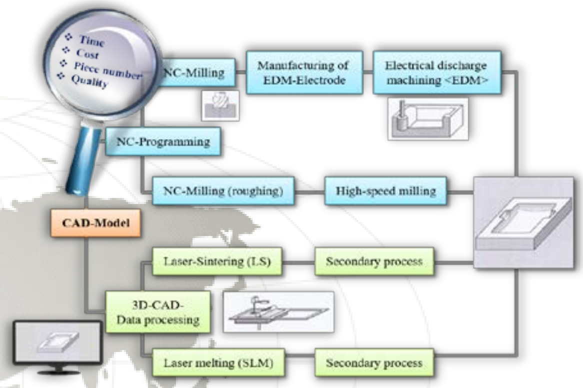

Figure 5 – Manufacturing variants of injection mold

- Evaluation of manufacturing variants according to time, cost and piece number
- Time-saving and cost-reducing application of feature technology from the design to the additive manufacturing
- Early influences on the technological manufacturing process (conventional and / or additive) in the production of prototypes
- Efficient and user-friendly application of the assistance system TAGAP by integration with existing CAD and ERP software
- Minimizing the variety of tools and tool stocks in companies by tool-free prototype manufacturing
- Sustainable application of experiential knowledge
- Increasing the transparency of costs in the prototype manufacturing
- Rapid manufacturing and cost-optimized production of prototypes and pre-series

NOTE: This paper is based on the paper presented at the International Conference Management of Technology – Step to Sustainable Production (MOTSP 2016), organized by the Faculty of Mechanical Engineering and Naval Architecture, Croatian Association for PLM and the University of North, in Porec/Parenzo, Istria, Croatia, June 01–03, 2016.

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