2nd Conference on Production Systems and Logistics

Potential Analysis of Flexible Small Series Production of Spare Parts by Direct Polymer Additive Tooling

Günther Schuh[1], Georg Bergweiler[1], Falko Fiedler[1]
Daniel Neumann[1], Lennart Heetfeld[2], Philipp Bickendorf[1*]
*Corresponding author (philipp.bickendorf@rwth-aachen.de)
[1]Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Aachen, Germany
[2]Chair of Production Engineering of E-Mobility Components (PEM), RWTH Aachen University, Aachen, Germany

Abstract

In recent decades, there has been an increasing creation of vehicle model variants and product individualization for customer needs. There is a need for a greater variety of spare parts which is leading to high requirements on their logistics. As a result of this trend, automotive production companies have to ensure the provision of many different spare parts as part of their post-fulfillment obligations. However, the surplus spare parts stock will increase the operation cost of the company. This implies the need for a more flexible approach to spare parts production and provision to improve profitability compared to existing process chains. In this research paper, the potential of flexible spare parts production and provision is discussed. For this purpose, the state of spare part production technologies and existing approaches for spare part service are analyzed regarding their technological characteristics, flexibility as well as cost structure. Following this, an approach for flexible production for spare parts with regard to its potential is analyzed and demonstrated based on three exemplary automotive use cases using additively manufactured production resources. In the casting use case, a Fused Filament Fabricated (FFF) additively manufactured speedometer screw model will be used as a sand casting form. The production of deep-drawn car body parts using polymer-based FFF forming tools is investigated in the second use case. Lastly, the production of ignition distributor caps by PolyJet Modelling (PJM) manufactured Injection Molding (PUR-RIM) molds is presented.

Keywords: Additive Tooling; Rapid Tooling; Spare Parts; Classic Cars; Small Series Production; Production System; Production Concept, Production Equipment; Automotive Production

1. Introduction

Enabling technologies have diverse technology-inherent annual quantity spectra and allow economical production of parts of different complexity in small series. In recent years, spare parts production and provision have gained importance and are becoming increasingly relevant in all production industries. For example, a typical problem in the automotive industry is the build-up of excessive spare parts inventories. This is done based on of flat-rate surcharges on forecast requirements, but not on actual demands. For this reason, Original Equipment Manufacturers (OEM) and suppliers tie up capital in an unprofitable way due to inflexible, conventional production of spare parts [1]. Similar problems can be seen in the case of classic cars, too. Despite an increasing number of registrations of classic cars, the demand for spare parts is severely limited. In addition, in many cases the original tools for manufacturing parts no longer exist, so that spare parts production and supply under conventional aspects prove to be unprofitable [2]. To be able to offer high quality spare parts at competitive prices, it is therefore necessary to identify the potentials of enabling

DOI: https://doi.org/10.15488/11244

production technologies, such as Additive Manufacturing (AM), that can be used to rebuild required tools or the part itself. For this purpose, production technologies must be analyzed and cost drivers identified. To enable a price evaluation of parts to be produced, a classification of parts must be created, which can be linked to the desired market prices. The identified cost drivers and the approximation of market prices can be used to evaluate the economic efficiency of the flexible production of automotive spare parts. Despite high expected cost of AM and uncertainties of its technological development, AM is promising a reduction of lead times, tool and storage cost as well as an increase in production flexibility [3].

Therefore, the underlying research question arises how significant the potential is for the use of Direct Polymer Additive Tooling (DPAT) in the production equipment manufacturing for spare parts and how potentials can be used. Hence, the research hypothesis of this paper is that Rapid Additive Tooling (AT) has a high potential for a cost- and time-effective production and provision of automotive spare parts with automotive-typical quality. Furthermore, a systematical scheme for the application of AT for production equipment in small series production can be conceptualized. To investigate this hypothesis, the current state of research is discussed. Deficits of existing approaches with regard to the industrial requirements of spare parts are described and potential solutions are presented. Based on this, a potential analysis scheme for the use of AM in production equipment manufacturing is conceptualized as well as demonstrated by three automotive use cases. [4,5]

2. State of the Art

Production of Spare Parts: A production system describes the appropriate combination of resources (material, energetic and spatial, as well as personnel and financial), information and competences for the manufacturing of products of a certain type and quantity at acceptable costs with a specified quality. Production can be understood as any combination of production factors, which thus encompasses the operational performance process and its corporate potential for production tasks can be derived [6]. This understanding of production systems has also been established in the automotive industry [7]. Due to the aftersales services, where typically about 22 years including the 10-year legal spare parts supply obligation elapse from the Start of Production (SOP) of the vehicle models to the End of Delivery Obligation (EDO), a production system is essential. In this system, spare parts are produced during the production phase of the models to compensate for early defects, followed by a consolidation phase with fluctuating demand for spare parts and a degeneration phase. Production is usually carried out by spare parts suppliers on the serial equipment used until then, i.e. with the help of equipment that is manufactured by casting and chipping, which are planning-time- and cost-intensive. After End of Production (EOP), the stocking of high-quality spare parts for the vehicle lifetime has to be foreseen, with the main difficulty being the long-term planning horizon with high uncertainties. [8]

Spare parts production follows the typical production understanding of the automotive industry with decentralized material provision, production and logistics, whereby lot sizes are often planned according to general ordering algorithms of business administration [9,10]. To counteract the uncertainties in planning, there is a move towards lean spare parts management as a logistical trade-off between provisioning, capital commitment and costs [11]. Spare parts logistics as the second aspect of spare parts provision alongside production is responsible for the supply of materials and information, procurement from the supplier as well as warehousing and finally provision at the point of need. In this context, replacement and consumable parts are scheduled and procured according to the same principle, without considering changes in defect or consumption characteristics. This often results in oversized safety stocks. [1] Expert statements underline the requirements for the quality of spare parts in the sense of the automotive understanding of production. Despite low unit demand and the desire for competitive costs, OEMs still rely on extensive technology exchange for R&D and internal storage of high volumes of spare parts. [12] This traditionally grown spare parts supply results in a high inventory capital and high investment costs in conventional tools (e.g. by casting and chipping) with an inflexible provision and strongly physical understanding, whereas current trends towards new value creation approaches such as the copyright on product and production data are hardly considered. The result is a low service level, even though the spare parts business holds enormous potential for success for OEMs. [10,8] The lack of flexibility in the provision of spare parts is a problem for classic cars, too. In contrast to the situation with current models, there are often no longer any series tools for classic cars and, due to the lack of digital product and production data, these cannot be easily reproduced. [8] Furthermore, the scattering of vehicles over the course of time makes the logistics processes of spare parts supply for classic cars even more difficult. Hence, the resulting costs from a conventional point of view for spare parts for classic cars are even higher than they are in the context of general after-sales services.

Enabling Production Technologies: In addition to conventional machining, enabling production technologies with great relevance have emerged as a result of technological developments. In the following, AM will be examined in greater detail. AM describes generative 3D printing in which objects are produced directly on the basis of Computer Aided Design (CAD) models. Manufacturing is accomplished by the layer-by-layer automated application of liquids, powder and filament material to produce true-to-scale 3D physical objects without the use of part-specific tools [13,14]. The printing process itself is thereby automatically determined by the computer based on the CAD, enabling the implementation of an end-to-end data process chain [14]. Meanwhile, all printers use the basic layer buildup approach, but the relevant parameters of the process for differentiation represent the materials used [13]. The build-up principle of AM thus allows complex product designs with material-dependent product properties and high dimensional stability, whereby variable part costs are mainly dependent, when neglecting the amortization of investment costs, on post-processing and material costs [15–17]. The most widespread AM technology is FFF, a process in which thermoplastic is heated above its liquefaction point and applied through a nozzle in layers to the object geometry. Advantages of FFF are that the use of support materials makes it possible to create very complex geometries that cannot be produced conventionally, e.g. by injection molding, and a very wide industrial and private distribution. Disadvantages are a lower surface quality and poorer mechanical properties of parts. PJM, a further widely used process, relies on photopolymers and thus achieves a higher degree of accuracy and greater variability of printing properties, which, however, also results in higher costs. Accordingly, the advantages of AM are short lead times after part design as well as rapid production of parts in the printing process and the elimination of some time-consuming process steps. In the following, DPAT as a subcategory of AM is of particular importance in the context of production tooling for the spare parts production and will be examined in more detail below on the basis of initial approaches from research and industry. [14]

Existing Research Approaches: The AM technology presented can be used in a variety of ways for spare parts provision in automotive industry due to the large number of different process and parameter combinations. In the following, an overview of some research approaches and industrial use cases of AM and AT for small series production and spare parts provision will be presented. The technical possibility and economic feasibility of AM and AT applications depend on production volume, part size, material cost and complexity. DPAT can produce equipment quickly and cost-effectively. This methodology has already been widely used in industry for several years and can be applied for the small-batch mold production of interior parts [18]. AT is cost effective with plastic injection molding of volumes around 1,000 parts [19]. Shaping tool elements can also be substituted by AT and research has shown potential its regarding the use in deep drawing, stamping and bending as well [20]. Additively manufactured tool inserts can be integrated into a modular pillar set out of conventional tooling steel [21]. In this way, deep drawing inserts can be manufactured for the use in small series of sheet metal parts with internal resources [5]. Furthermore, intensive research is being conducted into the further development of AM materials. E.g., material combinations of FFF filaments enable the production of parts with a stiffness comparable to that of aluminum. [22] The logic of substituting shaping tool elements can be applied not only to other production equipment (such as welding jigs or assembly aids), but also to other production technologies (such as AM of sand cast model and core box model). Research for large-scale industrial applications is being carried out, e.g. at Volkswagen's Portuguese plant, where most assembly jigs are being produced internally with the help of AM instead of external partners. Further approaches for e.g. fixture design specifically for electro mobility are also being researched and continuously developed [23–25]. In addition to the existing approaches for AT, reference should also be made to the direct printing of spare parts. OEMs are producing e.g. mechanical parts in small batches, particularly in the luxury segment: Bugatti produces AM brake calipers from titanium for series equipment. For spare parts production, the Volkswagen Group started to produce individual AM of release levers for the clutch as spare parts e.g. for the Porsche 959. This results in a broad field of initial application areas for AM/AT in the automotive industry for series and spare parts requirements [26].

3. Analysis of the Spare Parts Supply Chain

Deficits of Supply Chain: In the following, the currently prevailing disadvantages of spare parts supply will be presented and the areas of application of possible new technologies will be shown. The challenge focused on in this paper is the integration of AT into prevailing structures. DIN 24420 is used to enable a clear distinction of parts, assembly groups as well as complete products as spare parts [27]. They are intended to maintain the function of a vehicle and can include both worn and missing parts [28]. Regarding demand patterns during the production, compensation and degeneration phases, a distinction of spare parts is made between wear and defective parts [28]. Wear parts are generally in high demand, which means that even after the EDO, procurement is usually possible without any problems. Wear parts are simple parts such as rubber bushings or brake pads [29]. The predictability and availability of wear and non-wear parts is good since they are mass-produced, statistics from previous models can be used as a reference. Thus, the post-fabrication options are usually unproblematic. In contrast, defective parts have a low request and the defect time is not well predictable ('spikes'). Defective parts are mostly parts which are highly innovative and complex. Electrical parts are mostly affected, due to the increasing amount of electric parts in the vehicle [29,30]. The production period is also usually very short, as these parts are expensive and therefore rarely kept in stock [31]. For this reason, attempts are made to replace defective parts with carry on parts or substitution parts [32]. From today's perspective, it can be seen that the older the vehicle or the higher the mileage, the more likely it is that not only mechanical parts but also body or interior parts will fail. The current spare parts situation varies depending on age, number of vehicles built and OEM. The supply of wear parts is fine. However, it can be seen that after EOP and EDO, there is a time when real demand for classic cars is met by other means. First of all, remaining stocks are used up or 'wrecked cars' are exploited. Conversions to non-original parts are also carried out to keep cars roadworthy. Only after these variants have been used up, a higher demand from the OEM becomes apparent. As an alternative, spare parts are also produced by private individuals or even interest groups (more common) to counteract bottlenecks.

Besides these general spare part supply activities, the classic spare part production starts normally after EDO respectively even further from the EDO. Vehicles must be at least 30 years old to be classified as a classic car and depending on era as well as category (mass/premium vehicle), the complexity of the vehicles and parts differ [33]. However, electrification was very limited in classic cars production and defective parts therefore are mainly mechanical or body parts. [33]. Currently, subcontractors are founded that take care of the spare parts procurement of classic cars. Here, following the above-mentioned general supply approach, the OEM buys up remaining stocks from suppliers or produces new parts with the help of existing tools. However, as this is very expensive and customers demand a high quality, more complex parts are slow to be reproduced. At some point, these supply solutions are no longer technologically and economically worthwhile and are provided for brand management and customer/fan loyalty [12]. In Germany, classic cars spare part demand can be forecasted well as the number of active cars is completely known [34]. For classic cars, a distinction must be made between visible and functional parts. Critical functional parts may deviate from the original part if there is no other way to keep the car roadworthy. Visible parts (non-critical) are usually not accepted if the quality deviates from original parts. Some wear parts for classic cars, such as shaft bearings or brake pads, are even still available, as they are widely used in other industries as well. Substitution is therefore also a possibility to fulfil one's need for spare parts.

Analysis of Enabling Production Technologies: Various approaches regarding e.g. process optimization, sustainability and the simulation of supply and demand of spare parts with the help of AM has been object of research so far, but no general approach for a production system for AT has been developed [4,3,20]. As mentioned in chapter 2, a distinction must be made between AM and AT. In AT, a shaping tool which is additively manufactured is used to form or cast the spare part. With direct AM, there are completely different materials or materials with comparable mechanical characteristics available to produce the spare parts. Choosing the use case specific combination of technology, process and material is important. Following this, potential advantages are reduced part or tool costs, shorter lead times, a high potential regarding automation as well as maximum potential regarding adding geometric complexities. AM is highly flexible and reworking parts is usually less compared to conventional production technologies.

The challenges are to increase process stability and implement the currently prevailing build volume limitations of AM in the best possible way. For classic car spare parts, the quality of visible and functional parts must also correspond to that of the original part. A closer look at the product life cycle reveals that AM/AT have applications in every phase. Due to technological boundaries such as print time and layer height, the technological and economic potentials are so far mainly enabled in small annual quantities. These mostly include the prototype, product development and spare parts sectors. Nevertheless, there is no systematic classification in automotive production concepts so far. [10]

4. Flexible Spare Parts Provision

Production Characteristics: In the following, use case specific characteristic values will be described and used as a comparison to conventional tooling. For the successful establishment of a flexible production of spare parts, it is essential to consider the potential of a manufacturing task within the overall corporate value creation context. A five-stage procedure can be used for this purpose: 1) Analysis of the spare parts portfolio and the need for production equipment 2) Challenging production processes and their potential for DPAT 3) Analyzing business cases 4) Derivation of AM strategy 5) Piloting of approach, validation and rollout [10]. With the help of six production characteristics defined in Table 1, a production company can assess such procedures.

Table 1: Production characteristics

Characteristic	Short description
Process	Process considers all elements of the service creation process that are necessary for part production (development, design and production of part & tool).
Materials	Materials include characteristics resulting from part and tool material choices. If the original material is not available, an at least equivalent quality level is to be aimed for.
Function	Function records which requirements exist for the part, e.g. functional requirements in terms of mechanical, thermal and chemical resistance or visual and haptic impressions.
Geometry	Geometry assesses part shape and dimensions. The focus is on geometric elements that increase the design effort or impose restrictions in terms of production technology.
Costs	The costs are divided into personnel costs, operating material costs, material costs and capital costs for the part as well as any necessary tools. It is assumed that the provision time of the tools resulting from the production process correlates with the costs.
Tool life	The expected quantity to be produced is considered within this characteristic. A tool is worn when the required part quality or dimensional accuracy can no longer be achieved.

On top of these six exemplary characteristics, further aspects as for example the original material, small batch quantities, reduction of tooling costs, use of conventional manufacturing process, and existing production facilities might need to be considered for a corporate-individual potential analysis as well. The exemplary outputs of this procedure will be described in the following and allows an evaluation of AT for flexible small series spare parts production based on these experiences. The main aspects of the potential of AT are summarised below.

Use Case 1 - Sand Casting by AM Mold Models: Typical cast components include engine components, transmission components, brake discs and housing components. The part manufactured in this use case is a speedometer screw (production date 1933) which is located near the wheelhouse and is mounted on a drive shaft that transmits the signal for display in the speedometer scale (cf. Figure 1). This shaft cover (defective part) encloses a drive shaft in which a magnetic disk rotates to indicate the vehicle's speed. At first, the original part is analyzed and the dimensions are determined by optical 3D scanning. When the manufacturing process was initially carried out, deriving the dimensions was difficult due to the deformation of the original component and required increased rework in reengineering a 3D model during CAD design. This is a common challenge for the reengineering of classic car spare parts. The next step is to prepare the FFF of the mold models. In sand casting, these mold models will be pressed into oil sand to leave the part mold for casting in it. The mold models are manufactured out of a wax filament with printing parameters that allow low material consumption, sufficient stiffness as well as an accurate and smooth surface. Using the AM mold models, the sand mold is prepared for investment casting. After removing the mold models, the aluminum will be poured in the sand mold by means of runners. Finally, the cast parts are subsequently cleaned and reworked. In the process, the sprue is removed as well as holes and a thread are inserted, which cannot be produced by sand casting. Because the molding model can be removed prior to the sand casting, it can be used as often as desired to produce a sand mold. The surface quality can be adjusted according to the AM quality and the degree of post-processing of the mold models and is therefore accordingly good. The manufacturing costs include the material, labor and machine costs associated with the part as well as the mold form. The detailed cost of eight parts is shown in Table 2. In terms of potential evaluation, it can be summarized that the tooling costs are significantly lower than for milled permanent metal models, and undercuts and internal geometry that normally generate significant additional work (core and core box) do not pose any problems when designed for AM and casting. Therefore, DPAT for sandcasting shows potential for small series production concerning the production characteristics process, geometry, cost and tool life from chapter 4.1.

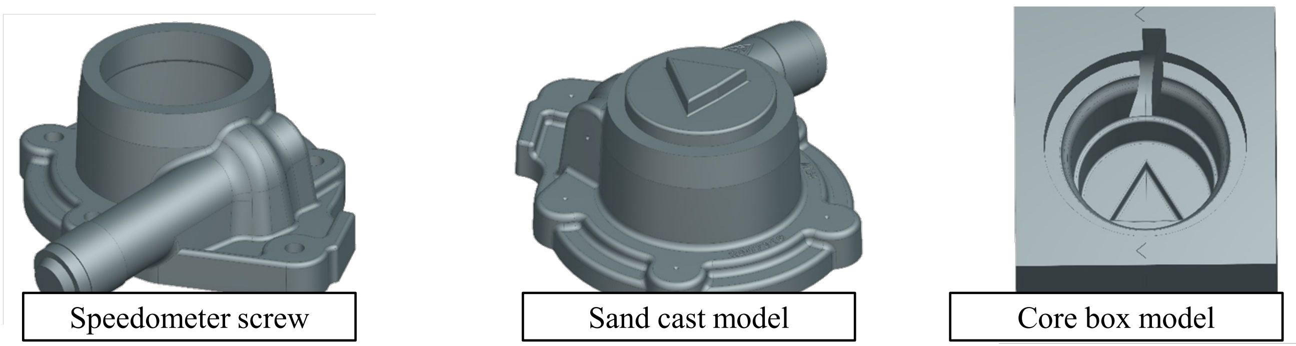

Figure 1: Speedometer screw and AM sand casting models

Table 2: Exemplary cost breakdown

Cost breakdown sand casting	Time needed [h]	Hourly rate [€/h]	Series costs [€]
3D scan (Labor + hour rate)	2.00	70.00	140.00
CAD design	20.00	50.00	1,000.00

1. Filament (PLA & Support)			6.00
2. Personnel (Plant operator)	1.00	25.00	25.00
3. Machine hour rate (Ultimaker S5)	2.50	18.40	46.00
1. Molding sand (Oil-based)			80.00
2. Aluminum (AlMgSi)			1.79
3. Labor (Plant operator)	12.00	25.00	300.00
Total cost for a small series of eight parts			1,598.79

Use Case 2 - DPAT for Deep Drawing: The part to be manufactured is a seatbelt retainer plate (defective part), which is installed on the inner B-pillar to reinforce the seatbelt attachment area. This is a typical crash-relevant small car body shell part out of sheet metal with small tolerances on joining and functional elements (+/- 0.5 mm) (cf. Figure 2) [5]. Following the design of the sheet metal part, the CAD model is extended by a seam for the blank holder [35]. A formability simulation with the help of Ansys determines whether the component is at risk of cracking, wrinkling or compression during the forming process. The layout and design of the tool can be derived with the help of Computer aided sheet metal forming add-ons. A FEM simulation was also carried out for the mold, which enables a CAD design optimized for the application. An influence that has not yet been fully quantified is the elastic-plastic deformation of the tool material. Based on experience from previous experiments, Polylactic Acid (PLA) is chosen for the FFF of the tool because of its good cost-per-stiffness value as well as easy processability. Due to the high quality of the print results achieved with PLA, post-processing was limited to the removal of the build plate adhesion as well as a reaming of the holes for the dowel pins. For the integration into the forming press, the tools were mounted on a pillar set. For a small series of 27 components, 16 blanks of 1 mm DC04 deep drawing steel and 11 blanks of 1 mm 5754 aluminum were laser cut. After deep drawing with no lubrication, the parts need to be cut by 3D laser cutting to achieve the final shape. The part has various geometry elements such as stiffener beads or joining flanges which are common for sheet metal parts. The part's outer sides have 10 mm radii, whereas the maximum drawing depth is 18.5 mm. The tool set consists of a punch, die and blank holder, which are printed one after the other due to build space constraints of the Desktop printer used. With the help of AT, a significant reduction in costs similar to the first use case can be achieved. This can be justified with a shorter tool life due to the material as well as friction and wear. The tool therefore shows potential regarding small series deep drawing applications by considering the production characteristics material, function, geometry, costs and tool life.

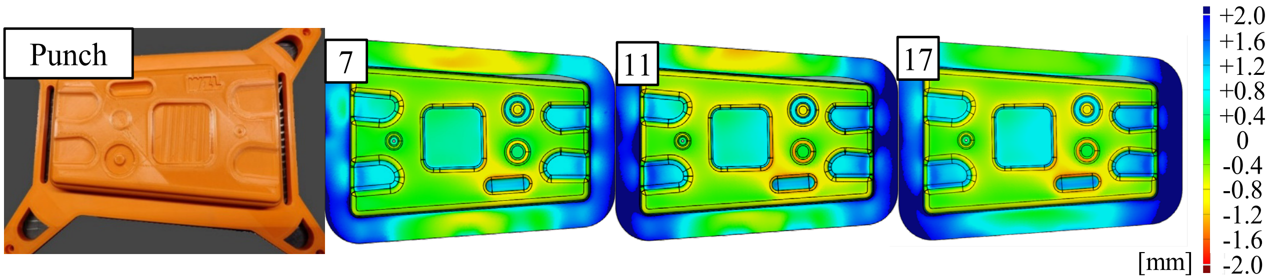

Figure 2: AM deep drawing tool and dimensional accuracy of sheet metal parts after forming operation 7, 11, 17

Use Case 3 - DPAT for Injection Molding: The part to be manufactured is an ignition distributor cap (wear part) produced by AM PUR RIM molds (cf. Figure 3). Scanning of the original component and reengineering is performed similarly to the first use-case. In the next step, a CAD design of the mold tool is created. The final injection molding then is printed using PJM. For the creation of a smooth surface, the cavity needs to be grinded in the post-processing. With the mold tool printed, the next step is to cast the ignition distributor cap using PUR RIM and subject it to post-processing, such as removal of the sprue and venting, before installation. During PUR RIM, a cast resign is used for the application of thin-walled and impact-resistant components. The material requirements result from the use in the engine compartment under corresponding thermal, mechanical and weathering influences. In addition, there is the requirement of a high optical as well as haptic quality with fine geometries for the component, which must be met in PUR RIM. Typical production of parts like this in the automotive industry takes place in annual quantities of over 10,000 and with short cycle times of about one second. In contrast, PUR RIM with the AM mold enables cost-efficient small-batch casting of the components with a high degree of design freedom, but at the same time also a limited range of application with regard to thermal and mechanical loads on the printed molds in PUR RIM. To meet these requirements for the mold, the two halves of the pattern used to manufacture the distributor cap were produced using PJM. By using release agents in PUR RIM, the mold can ultimately be reused for up to 50 cast parts before the required quality can no longer be maintained by the printed mold. For further evaluation, critical aspects are temperature resistance and surface quality of the mold configuration. Regarding the six production characteristics from chapter 4.1, the small series potential can be derived. Thus, the use of AM in injection molding is already established in some industrial applications.

Potential of AT: According to the preceding use cases, AT offers some advantages despite a lack of experience, which are summarized below. AT can usually meet the high requirements for the originality of components better than AM, especially regarding the use of material. Depending on the AM process, only a certain selection of materials can be processed. AT reduces the economic risk compared to milled steel tools, as tooling costs and provision time are minimized. It is more profitable than AM in small to medium quantities, especially quantities of 8-15 parts can be represented well using AT. The disadvantage of AM is that part costs remain almost constant across the quantities. Experience with AT can be transferred to many other use cases such as prototyping or product development. Existing production equipment and facilities can be used. Furthermore, the conventional production process is used, in which empirical knowledge and human resources are already available. This facilitates possible homologation or certification procedures.

5. Conclusion

Summary: In this paper, the potential of DPAT in the spare part production and supply is analyzed. This is done by analyzing existing spare part production chains as well as presenting three use cases with additively manufactured tools. The examined use cases are evaluated on the basis of six production characters regarding Process, Materials, Function, Geometry, Costs and Tool life for both, wear parts and defective parts. In the first use case, a surface optimized FFF-ABS sand cast model as well as core box model will be used as

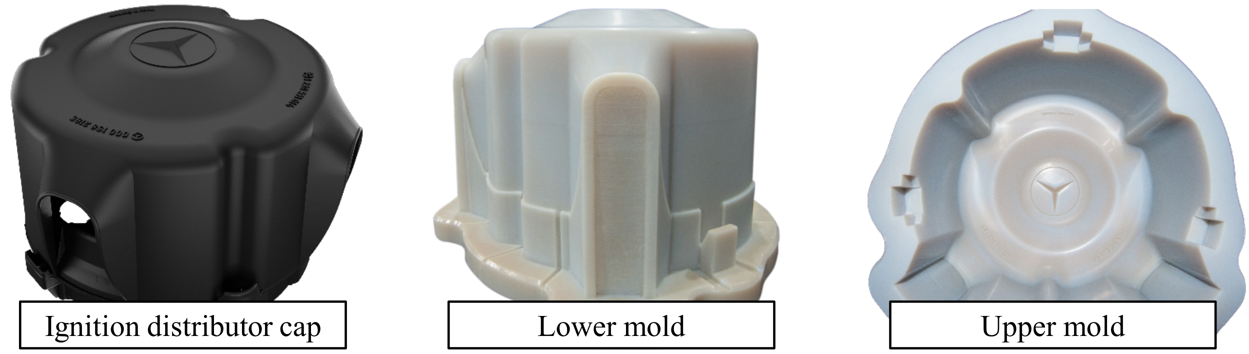

Figure 3: Ignition distributor cap (spare part) and AM injection molds

production equipment for the small series sand casting of a speedometer screw. The production of cast molds is making use of the high degree of geometrical freedom of AM. In the second use case, a small series of small sized car body parts are deep drawn with an AT setup out of FFF PLA. The tool life is sufficient for the production of 17 seatbelt retainer plates out of 1 mm DC04 steel. Stiffness and wear resistance of such tools is limited so that deformation and wear play a major role. FFF is suitable for the production of forming tools for small series and spare parts applications, because of the low investment, process and material costs. A distributor ignition cap is manufactured with injection molding (PUR RIM) in the third use case. The PJM of Digital ABS material was used to manufacture the upper and lower injection molds needed for the production. Due to the complex geometries and the time-consuming reverse engineering, this is the most complex use case in terms of time, costs and requirements. Overall, AT shows promising results in specific use cases for the improvement of spare parts production and supply. Especially for the supply of classic cars, which are not supplied by the OEMs after EDO, AT can speed up production and reduce costs of small series. So far, AM has shown potential regarding the direct AM of spare parts mainly due to the non-necessity of shaping elements and tools. But in the case of AT, components can be cast or formed in the original materials in conventional quality. In addition, the mechanical characteristics of additively manufactured production equipment can be adapted according to the specific local load with the help of a broad variety of AM materials. Based on the demonstration of three use cases, a high potential for the use of DPAT for the production of spare parts can be observed. The systematic approach with an organized framework regarding the production characteristics might be a promising approach for spare parts provision.

Limitation: The scope presented is limited to the analysis of conventional production technologies with the great importance in spare parts supply such as metal casting, deep drawing and injection molding. By replacing conventional manufacturing of production equipment with A, process limits of the tooling configurations are changed. Thus, new competencies have to be built up with respect to the shifted process boundaries. So far, AM is only used for the production of mechanical parts such as housings, caps or car body parts. A potential analysis of the production of electrical, electronical and mechatronic parts needs to be done.

Outlook: Further production technologies in which AM show potential are hydroforming, rubber pad forming, investment casting and bending. In hydroforming, parts of the highly complex tooling set can be manufactured by AT. Elastic AM materials are used in rubber pad forming to print the rubber pad, which can be used flexibly for different forming geometries compared to deep drawing. In investment casting, filaments can be used to print the lost form models, which evaporate in contact with the casting material in a similar way to the wax previously used for this purpose. The design flexibility of AM allows complex geometries to be created. In other forming processes such as bending, various high-stiffness AM materials can be used to replace series steel tools. Furthermore, the tool deformation prediction is further investigated. For this, a database by evaluation data from further experiments can be created. The results are transferred to new geometries on different parts to accelerate the design. The portfolio can be expanded regarding other parts such as profiles. AM is also enabling potential regarding the connection with digital business models. Spare parts can be produced on demand with the help of AM/AT process chains. For the confirmation of the industrial suitability, various use cases can be integrated in real production environments.

Acknowledgements: We wish to acknowledge the BMWi for funding the project 'LeSS'.

References

[1] Pawellek, G., 2016. Integrierte Instandhaltung und Ersatzteillogistik. Springer, Berlin, Heidelberg.

[2] Hamill, S., 2020. 3D Printed Car Parts: The Savior of Classic Cars | 3DSourced.

[3] Knofius, N., van der Heijden, M.C., Zijm, W.H.M., 2019. Moving to additive manufacturing for spare parts supply. Computers in Industry 113, 103134.

[4] Bergweiler, G., Heinze, F., Lichtenthäler, K., Bickendorf, P., 2020. Ressourceneinsparung durch additiv gefertigte Umformwerkzeuge und Schweißvorrichtungen. ATZ Produktion 7 (1).

[5] Schuh, G., Bergweiler, G., Fiedler, F., Bickendorf, P., Schumacher, P. Small Series Production and Geometric Analysis of Sheet Metal Car Body Parts Using Forming Tools Made of FFF PLA. IEEM, 156–160.

[6] Westkämper, E., 2006. Einführung in die Organisation der Produktion. Springer, Berlin, Heidelberg.

[7] Kampker, A., Bergweiler, G., Hollah, A., Bickendorf, P., Hoffmann, F., 2019. Development of a framework for the flexibility assessment of automotive production concepts. Procedia CIRP 81, 34–39.

[8] Klug, F., 2018. Logistikmanagement in der Automobilindustrie. Springer, Berlin, Heidelberg, 528 pp.

[9] Biedermann, H., 2008. Ersatzteilmanagement. Springer, Berlin, Heidelberg, 159 pp.

[10] Geissbauer, R., Wunderlin, J., Lehr, J., 2017. The Future of Spare Parts is 3D, 2017.

[11] Guo, D., Yu, X., 2018. The Lean Management of Spare Parts in Automotive Manufacturing. MATEC 214, 4005.

[12] Bickendorf, P., 2020. Innovationspotenziale für die Ersatzteilproduktion bei deutschen OEM.

[13] Dudek, P., Rapacz-Kmita, A., 2016. Rapid Prototyping: Technologies, Materials and Advances. Archives of Metallurgy and Materials 61 (2), 891–896.

[14] Fastermann, P., 2016. 3D-Drucken. Springer, Berlin, Heidelberg.

[15] Atzeni, E., Iuliano, L., Minetola, P., Salmi, A., 2010. Redesign and cost estimation of rapid manufactured plastic parts. Rapid Prototyping Journal 16 (5), 308–317.

[16] Franchetti, M., Kress, C., 2017. An economic analysis comparing the cost feasibility of replacing injection molding processes with emerging additive manufacturing techniques. Int J Adv Manuf Technol 88 (9-12), 2573–2579.

[17] Schröder, M., Falk, B., Schmitt, R., 2015. Evaluation of Cost Structures of Additive Manufacturing Processes Using a New Business Model. Procedia CIRP 30, 311–316.

[18] Schuh, G., Bergweiler, G., Lukas, G., Abrams, J.A., 2020. Feasibility and Process capability of polymer additive injection molds with slide technology. Procedia CIRP 93, 102–107.

[19] Sedacca, B., 2011. Hand built by lasers: Additive layer manufacturing. Engineering & Technology 6 (1), 58–60.

[20] Nakamura, N., Mori, K.-i., Abe, Y., 2020. Applicability of plastic tools additively manufactured by fused deposition modelling for sheet metal forming. Int J Adv Manuf Technol 108 (4), 975–985.

[21] Schuh, G., Bergweiler, G., Bickendorf, P., Fiedler, F., Colag, C., 2020. Sheet Metal Forming Using Additively Manufactured Polymer Tools. Procedia CIRP 93, 20–25.

[22] Bergweiler, G., Fiedler, F., Kampker, A., Lichtenthäler, K., 2019. Additiv gefertigte Umformwerkzeuge im Prototypenbau. Umformtechnik 2019 (3), 18–19.

[23] Kampker, A., Bergweiler, G., Hollah, A., Lichtenthäler, K., Leimbrink, S., 2019. Design and testing of the different interfaces in a 3D printed welding jig. Procedia CIRP 81, 45–50.

[24] Lichtenthäler, K., Bergweiler, G., Kampker, A., Hollah, A., Leimbrink, S. AM for Cost Efficient Hybrid Welding Jigs, 559–571.

[25] Schuh, G., Bergweiler, G., Lichtenthäler, K., Fiedler, F., La Puente Rebollo, S.d., 2020. Topology Optimisation and Metal Based AM of Welding Jig Elements. Procedia CIRP 93, 62–67.

[26] Volkswagen AG, 2018. Bremssattel und Räder? Jetzt aus dem 3D-Drucker!

[27] 1976. DIN 24420-1:1976-09: Ersatzteillisten; Allgemeines.

[28] Dombrowski, U., Malorny, C., Kolshorn, R., Blöcker, T., 2008. Teiledienst, 35–124.

[29] Nyhuis, P., 2008. Beiträge zu einer Theorie der Logistik.

[30] Roland Berger Strategy Consultants, 2010. Industrieservices in Deutschland.

[31] Livingston, H.C., 2002. GEB1: Diminishing Manufacturing Sources and Material Shortages (DMSMS) Management Practices.

[32] Dombrowski, U., Fochler, S., Malorny, C., 2020. After Sales Service. Springer, Berlin, Heidelberg.

[33] 2020. FIVA Technical Code 2020: Protecting, Preserving and Promoting the use of Historic Vehicles.

[34] Verband der Automobilindustrie e.V., 2021. Der Deutsche Oldtimer Index.

[35] Dietrich, J., 2018. Praxis der Umformtechnik. Springer, Wiesbaden.

Biography

Prof. Dr.-Ing. Günther Schuh (*1958) is head of the Chair of Production Engineering at WZL at RWTH.

Dr.-Ing. Georg Bergweiler (*1981) is head of the department Vehicle Production at WZL at RWTH.

Falko Fiedler, M.Sc. (*1988) is group lead Body Shop at WZL at RWTH.

Daniel Neumann, B.Sc. (*1996) is a student research assistant at WZL at RWTH.

Lennart Heetfeld, M.Sc. (*1991) is a research associate at PEM at RWTH.

Philipp Bickendorf, M.Sc. (*1992) is a research associate at WZL at RWTH.