STUDY OF OPPORTUNITIES FOR METAL ADDITIVE MANUFACTURING (MAM) TECHNOLOGIES IN TOOLING SECTOR

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INDEX

1. INTRODUCTION

Following the results of Activity 1.1, this document intends to analyze different potential applications in the tooling sector and it is a part of Activity 1.2 (“Study of Opportunities for MAM technologies in tooling sector).

A set of opportunities for development and improvement of the current Metal Additive Manufacturing (MAM) technologies in the industrial sectors will be identified, as well as indications on potential novel applications. This activity is key for the future definition of case studies.

As stated in Activity 1.1 and the brief description of the WP, partners will work closely with local partners of their region in defining the most relevant technological challenges and opportunities in the scope of the tolling and moulds sector.

This collaboration will entail:

1. The direct contact with entities identified during activity 1.1, by means of technical meetings and visits to the facilities, to assess the particular needs of each company.

2. Representative levels of information and identifying metal additive technologies having the most impact for the tooling sector, in the future.

These trends will be the foundation to define the case studied at activity 1.3.

2.AM TECHNOLOGICAL OFFER

2.1. Motivation and Potential

Additive manufacturing (AM), also known as 3D printing, enables the manufacturing of complex designs, remote production, weight reduction, high speed, and mass customization. Metal utilization is optimized in 3D printing, which uses layer-by-layer manufacturing as per requirement. 3D printing reduces the cost of overheads required for manufacturing, while also cutting down manufacturing time significantly.

Features such as the ability to manufacture lightweight designs, enhanced efficiency in the use of raw materials, the capability to produce objects with high mechanical strength, improved freedom of design, reduced production time, and freedom of customization are some factors encouraging businesses to invest in the technology. Many small- and medium-sized organizations are increasingly turning towards 3D printing for the development of customized products [01].

Metals are generally used in the 3D printing of products requiring high strength, stability, chemical resistance, and heat resistance. 3D printing uses metals for the manufacturing of various prototypes, spare parts, and functional parts across varied industries such as aerospace, automobile, defense, medical and industrial.

In addition to these facts, the AM bring new methodologies and new production capacities that so far were limited by using conventional subtractive production processes and opening new frontiers to the life cycle of equipment and components. This allows you to extend the life of the parts in service through innovative repair methodologies or through the production of replacement parts without the need for tools in many cases already slaughtered

Through the combination of virtual product design, including CFD, FEM and other numerical analysis tools, and the application of optimized design principles for AM, it is possible to explore the true potential of the additive production.

In this context, main **benefits** of additive manufacturing comparing to subtractive manufacturing would be the following [02]:

- There is no need for production tools, fade-out time to "ramp up" production;
- Small "batches" of production are feasible and economically viable;

- Design changes made easy and quick to implement;
- Product optimization focused on function (e.g. cooling channels optimized);
- The ability to produce complex geometries;
- Potential to simplify the supply chain industry, smaller delivery times, lower inventory dimension.

As technology improves and processes are refined, Metal Additive Manufacturing has grown increasingly popular and accessible. But even as price points for 3D printers come down and new applications for additive manufacturing are discovered, challenges remain that prevent many companies from utilizing this innovative technology to its full potential. In its recent survey of manufacturing decision makers – "3D Printing Trends Report" – Dimensional Research found that 96% of manufacturing stakeholders face challenges in 3D printing (Figure 1).

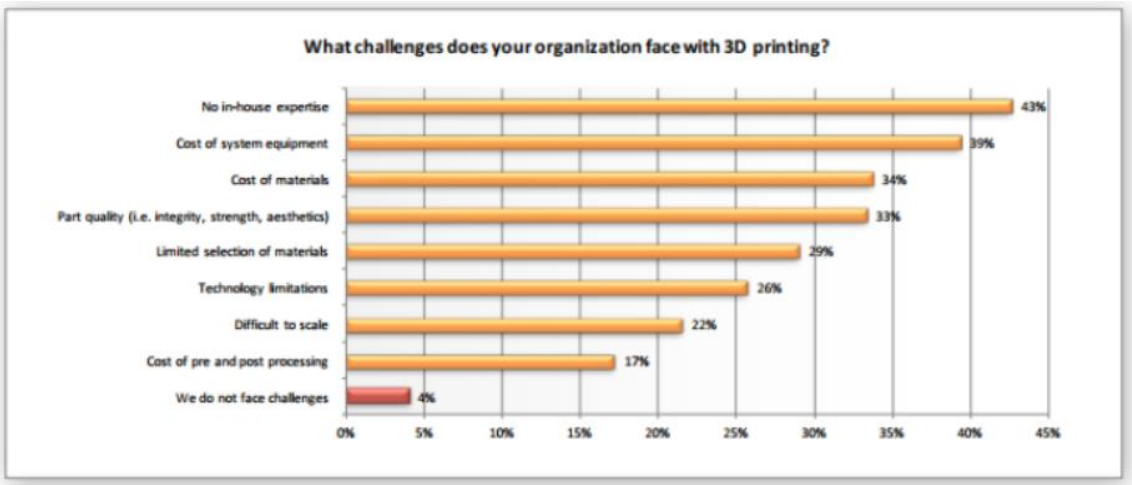


Figure 1. Challenges for Additive Manufacturing [03]

The top four challenges cited by respondents are: no in-house expertise, cost of system equipment, cost of materials and part quality:

No in-house expertise: Perhaps one of the most significant deterrents to utilizing Additive Manufacturing printing for many organizations is the technology itself. While few manufacturing companies will question the merits and value of metal additive manufacturing, many lack personnel with the wide variety of skill sets and training required to successfully make parts with metal 3D printers.

Cost of system equipment: While 3D metal printing technology has made significant strides over the last few years and the market is gathering a tremendous amount of steam, driving the cost of equipment down by as much as 30% in some cases, printers are still not affordable at $100,000 and up. Considering each printer can make only low volumes, many printers are required to scale up production. As a result, cost remains a significant barrier for those seeking a budget-friendly manufacturing solution.

Cost of materials: Materials often account for a significant line in a manufacturer's budget. According to Dimensional Research, tooling manufacturers are especially impacted by material cost and more likely to face issues around the selection of available materials.

Part quality: Not all metal 3D printing services and parts suppliers are created equal, and for this reason part quality remains a significant concern for manufacturers. Part-to-part and machine-to-machine repeatability is extremely difficult with DED, DMLS, SLS, or EBM.

Within this framework, European research activities are currently focused on studying the effect of feedstock, AM process parameters and post-treatments on resulting properties of parts. Moreover, another important goal is defining process and supplier qualification procedures and standards for manufacturing of AM components.

2.2. Foresight

It is expected that manufacturing in 2050 will look completely different as it is moving from cheap mass production to personalised production, adapting to changeable global markets [04][05]. These technologies enable clean production, by energy and material efficiency. During last years, AM industry have moved from prototyping to production, where quality requirements and complexity are much greater. After then huge investment was done in research and commercialisation. Many equipment manufacturers have appeared since 2015 and it will continue advancing impressively into the next years [06].

The scarcity of raw materials, big data [05] bases availability and product customisation trend make AM a perfect alternative to conventional manufacturing. The foresight of AM pays attention to different points to improve this technology in terms of making viable in an industrial scale:

- Productivity and flexibility
- Data collection
- Quality standardisation
- Material availability
- Multidisciplinary teams and training programs

Recently, an analysis of the market size of Metal 3D printing has been performed by Polaris Market Research [01] showing the potential of MAM over the next years and depending on the region (Figure 2).

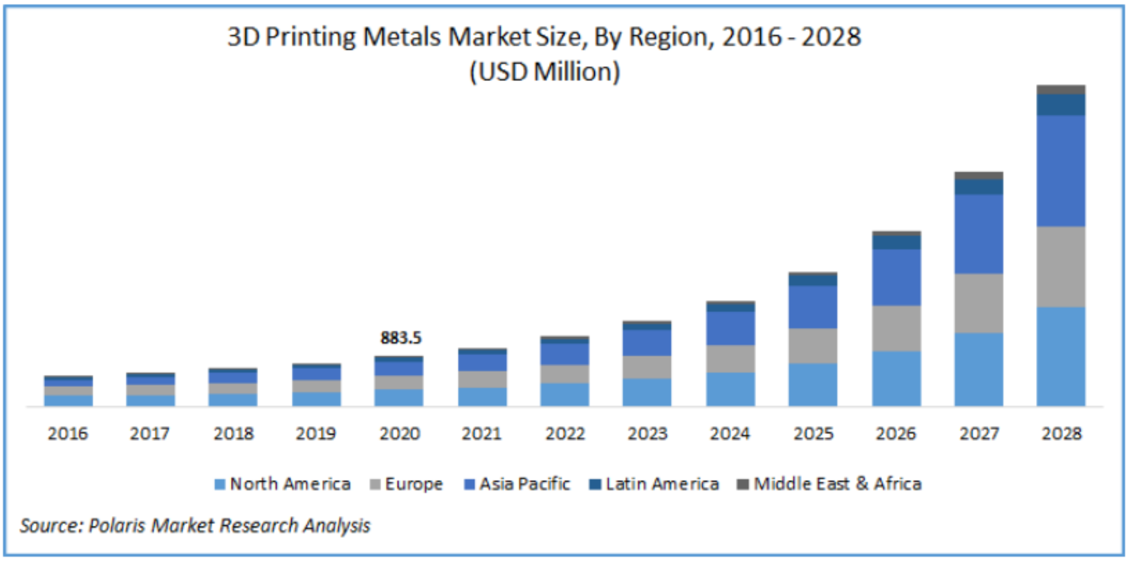


Figure 2. AM Market size [01]

The high costs of AM equipment can be justified by higher manufacturing speed, bigger chambers and easiness for load or unload of parts among others. To increase the deposition rate and productivity, main solutions are focused in different key points. As example lasers with higher power are being implemented. Also multi-laser equipment using more than one laser is being employed to work in parallel or to follow different strategies like skin-core strategies which use a high power laser to build the core and another one with lower power to build the skin which needs better precision. Multi-spot array systems mounted in a printer-like processing head with fume removal and local shielding gas is also being used due to the advantages like high manufacturing speed and no chamber size limitations. Also, the concept of full powder bed illumination or multi-jet fusion is in its final development stage. This system uses chemical agents to reduce or amplify the melting process achieving high surface accuracy, and masks to control the laser radiation. Another option to reduce process time is the use of novel systems that make possible a faster powder deposition or to make simultaneously deposition and melting processes.

Surface roughness and accuracy can be optimized by a post treatment like milling, polishing and/or machining. For this purpose, hybrid machines integrate additive manufacturing and machining which increase the productivity and reduce timeouts. Also modularization and integration concepts provide flexibility combining and integrating peripherals, bigger fabrication chambers, post processing and an automated handling or unloading station which can reduce considerably costs of production

Good quality in complex components are difficult to achieve. For that it is important to create and follow methodologies to select the appropriate parameters and strategies for different materials. The integration and communication between machines, for data collection and analytical programs for their management, are of high importance. Besides, simulation is a useful tool to predict and control the distortions, residual stresses and microstructures, limiting the number of experiments.

In the field of control monitoring systems, different methodologies have been developed to assure a robust fabrication process without differences in terms of quality and dimensions between batches. Chamber process control provides monitoring of any irregularity during the layer deposition but also the physical parameters of the laser and the oxygen level and pressure of the atmosphere. Melt pool process control provides monitoring of the temperature and shape of the melt pool in real time with the aid of high-resolution sensors. This improves traceability, quality, reliability, repeatability and efficiency. There are also simulation software programs that predict the melt pool and the behavior of metal powder.

In the other hand, non-destructive tests (NDT) assure the quality of the fabricated components. In this field, computed tomography is a useful tool to detect porosity in complex geometries. Due to the youth of AM for final metallic parts, specifications for inspection are still being developed and many manufacturers of inspection methods have been recently developed exploring new methodologies for AM [06].

Optimisation of topology design has to be improved by specialised software. Designers will change their designing way to a more functional way and less manufacturing way giving them more freedom to design. Topology optimisation software enables optimised and efficient designs with reticular and bionic-like structures applying mathematical algorithms. In reticular structures, materials are only added to the useful zones achieving rigid structures with the optimisation of the weight, which reduces the metallic powder consumption and manufacturing time.

The number of available materials continues growing. However, an increment of the materials choice is necessary. Developments are being done in the processability of new metallic materials like Ni super alloys, Al alloys, refractory metals and martensitic steels among others. Generation of data bases of the properties of specific materials built by AM and different processes may provide information for the design of proper new alloys for AM.

EXMET developed a process to build glassy metal parts by AM. Glass metals combines in a unique way properties like high strength, elasticity, hardness, corrosion resistance, conductivity and biocompatibility, all of them very useful for future high value application in electronics, aerospace and mechanical engineering [68].

A new manufacturing process to build multi-material components for specific functions is emerging. They are based on the material transition in a body during the manufacturing process. They have to exhibit compatibility between both materials. They can be made in two different chambers or by changing the feed by combination of 3 different materials in different proportions.

In the field of powder manufacturing, the tendency is to reduce the price of powders and to increase powder volume production. METALYSIS is a new powder manufacturing process using electrolysis. Its advantages are the cleanness, low energy consumption and cost reduction of 75 % [07]. However, a methodology to validate powder manufactured by new technologies is required. Also. a deep study on the influence of recycling or reusing powder maintaining good properties of built parts is necessary.

Future requirements include educational and training programs, as a key point to provide skilled workers, as well as the creation of multidisciplinary teams to develop complex products by AM [04]. To achieve this, educational training design, focused on metal AM techniques and technology, from junior to middle school, university and job training are of high importance to include different roles and great number of qualified professionals in this field [06].

If we take into consideration AM development brake and levers, next points must be contemplated:

- Qualification, standardization and repeatability of processes
  - Lack of reliability and repeatability of parts manufacturing. Many parameters influence the production, difficulty in taking them all into account. Mechanical, thermal, thermo-mechanical phenomena appear and anticipating them is a difficult task.
  - Also, Problems with low repeatability of the technical specifications from one batch of material to another, must be considered
  - In terms of standardization, standards are currently being written. Some are already accessible, particularly on powder bed technologies, on the other hand DED processes are still late.

- Improvement of the couple production speed / cost of production
  - The cost of part manufacturing is still too high to be currently competitive in series production.
  - The adoption of Additive Manufacturing technologies is only possible if a balance is found between manufacturing speed, production cost and the quality of the finished product.
  - Surface finish and post-treatment: Additive manufacturing today does not make it possible to produce parts with a good surface condition, especially for DED processes (Wire Laser, Wire Arc, Powder Laser, etc.)

2.3. Impact & opportunities:

The use of additive manufacturing can profoundly alter supply and manufacturing chains, historically outsourced and centralized. Even if, for many standardized products, traditional mass production remains and will always remain the most advantageous option (at least in the short and medium term), additive manufacturing techniques represent a great opportunity and apply in particular:

- Parts involved to supply disruptions
- Parts for which the need is limited but for which the minimum order volume from suppliers is high

- Low consumption parts requiring a mold whose manufacture is slow and expensive
- Parts and subsystems intended for repair and maintenance.

Also, proper identification of the skills and resources available in the different territories is essential for establishing enhanced cooperation between different actors, which reduces the cost of access to these technologies.

The emergence of additive manufacturing technologies thus invites new collaborative initiatives. The latter concern the business world and the regions, in particular by favoring short circuits and by sharing design methodologies and skills within the industrial ecosystem.

In order to ensure the maintenance and sustainability of these different ecosystems, the definition of a national and regional policy must be a priority in order to ensure that the issues and initiatives of each industrial ecosystem are properly taken into account.

On the other hand, some general opportunities for MAM are summarized below:

Prototyping and experimentation: The technology has mainly developed over the past thirty years. Rapid prototyping, rapid tooling (reduction of the cost and production time of a prototype that does not necessarily have a complex geometry) or the validation of pre-series (thanks to rapid tooling in particular) have made it possible to reduce times development, increase product quality and reduce costs on existing products without changes in the supply chain.

Industrialization of customization: MAM processes open the way to more flexibility in the configuration of the production tool. It is thus conceivable to integrate easily customizable parameters into an industrial production chain, making it possible to meet specific needs. The industrial implementation of the process thus opens the way for new interactions between the end user and the production chain, in order to offer the most suitable response to each need.

Series production and performance gain: additive manufacturing has the advantage of being able to produce complex shapes (which would not be possible to manufacture otherwise at a reasonable cost), or of integrating additional functionalities to reduce the assembly steps. This strategic focus is certainly the most important today for many stakeholders who want to increase their capacity for product innovation. Technologies make it possible, for example, to produce complex tooling in order to increase production rates or to integrate electronics from manufacturing without transforming the logistics chain.

Evolution of the value chain: additive manufacturing has a potential durable impact on the supply of materials or on the management of storage units, especially with regard to spare parts. The interest of additive manufacturing is not linked here to an improvement of the product but rather to an increase in the quality of service, combined with a new mobility of production tools. Opening the way to new economic models, this development axis can be envisaged over a longer period than the others but combines several advantages. It offers the possibility of a gain in competitiveness, a better competitive positioning, while allowing the creation of innovative economic models for production as close as possible to demand.

The most promising segment over the 5-8 year horizon seems to be tool manufacturing, insofar as the current level of maturity of the technology makes it possible to increase the performance of production lines in a process of continuous improvement.

2.4. The market opportunity

Although currently most of the overall activity on AM use polymer-based systems, there has been a good deal of activity and interest, with regard also to metal fabrication. Metal fabrication has sparked interest mainly due to the possibility that features direct manufacturing of components "near-net-Shape", and in some cases even final components, without the need for tools or machining. There has been particular interest in aerospace, automobile industry, especially of low grade, and biomedical industries, due to the possibility of production of high-performance components with reduced total cost of production. Researchers and industry leaders in the European Union (EU) have identified the AM as an emerging technology key.

Different countries outside the EU have increased their awareness of AM technology since for years and, at this point, North America is at the forefront when it comes to the adoption of AM. However, the importance given to these systems and technologies tends to spread quickly to other countries, putting the AM in the center of the development of their national jurisdiction. Yet, the situation of different countries in Europe is not homogeneous.

The selection and use of certain material is fundamentally defined by the end use requirements, however is also influenced by additive technology used.

The different additive production technologies present on most of the possibilities of using similar materials. In this way the titanium and nickel-based super alloys (for example Inconel) high-strength and stainless steels are the materials most commonly using additive production-this way seeks to take advantage of additive production to process expensive materials, which are hard to machine, seeking to benefit from the additive production by removing economic benefits from the reduction of material used and the reduction in production time of the components.

The technologies based on laser, beam of electrons and plasma arc probably can process the majority of metals, but still require some research to ensure full understanding and mastery of each of these processes for each of the available materials, leading to the industry to focus on processing the materials you want to economically more attractive by conventional processing difficulty. The processes of deposition of powder material present enormous potential since they can use multiple nozzles of deposition of materials allowing to change the chemical composition of the deposited material, within the same piece, in addition to deposition ratios and different precision depending on the size and use of the piece [08].

2.5. Tooling sector trends on AM

The tooling sector industries use mainly subtractive processes (termed chip metal cutting, or just machining) to produce tooling, independent of their type and application. This is because these ensure the required dimensional accuracy and surface finish.

Additive Manufacturing technologies, and particularly Metal Additive Manufacturing, can play an important role in optimizing several aspects of this industry. However, they still have known limitations regarding surface finish and mechanical properties. Therefore, the combination of additive with subtractive manufacturing processes has been the subject of several academic and research studies, showing a significant increase in its use in an industrial context. This combination is called Hybrid Machining.

2.5.1. Hybrid Machining

The compatibility and complementarity of additive manufacturing and subtractive manufacturing implies that they do not need and should not be mutually exclusive. To leverage all the potential synergies of additive and subtractive manufacturing technologies, hybrid machines, which incorporate Computer Numeric Control (CNC) subtractive technologies and additive manufacturing, enable the use of both in the ideal proportions needed for each case.

Despite advances in the field of additive manufacturing, its productivity is still much lower when compared to CNC machining. This fact encourages an increase in the productivity of this technology, which implies the following dilemma: inherent in all planar layer-by-layer additive manufacturing methods is the compromise between the desire for a quality surface finish without sacrificing productivity and vice versa, as illustrated in Figure 3. This dilemma can be translated into the choice between "high speed" (high productivity) and "low speed" (high quality surface finish), but never both at the same time.

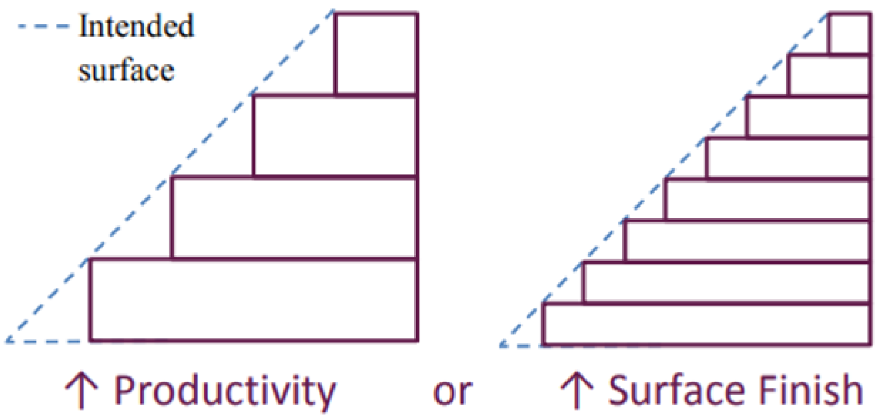


Figure 3. The productivity dilemma of additive manufacturing: is it better to have increased productivity or improved surface finish [01]

The option of hybridization of machines brings an answer to the dilemma presented, combining deposition by addition with subsequent subtraction by machining, thus independently controlling the productivity and surface finish variables, as illustrated in Figure 4.

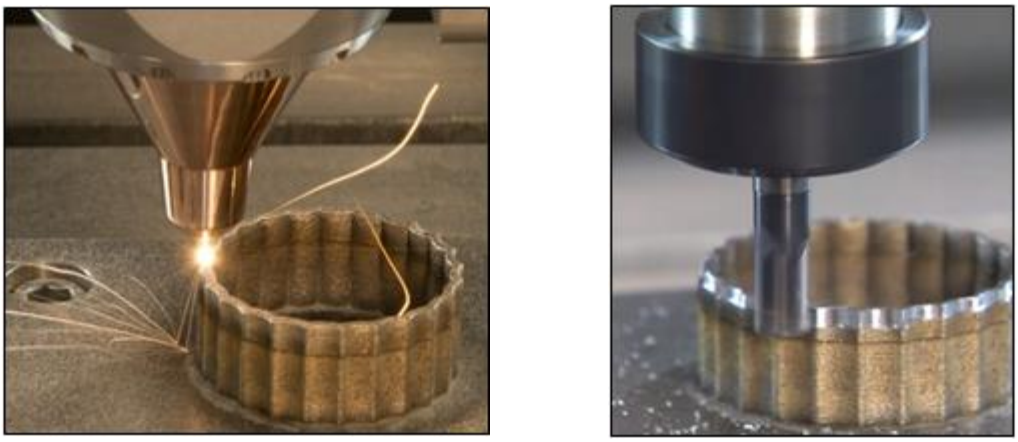


Figure 4. The synergy between the additive and subtractive process [10]

The use of additive manufacturing in tandem with machining processes is currently standard practice for most metal parts produced by additive manufacturing to achieve the desired surface finish.

However, even when responding to the above dilemma, it requires substantial investment in different machines and operators, so additional ways to reinforce synergies between the two technologies have been the subject of research and development.

To provide the transfer between the technologies involved, the ideal solution is then to incorporate a deposition system directly in the CNC milling machine, thus combining productivity and surface quality resulting from the hybridization of the process with the flexibility of centralization in a single machine.

Several tool manufacturers are already operating in the additive manufacturing market, using both DED and PBF technologies. However, when it comes to hybrid machining systems, the availability of machines based on DED technology is substantially higher when compared to those based on PBF technology. The reason for this greater availability is due to the higher deposition rate offered by the DED technology combined with the possibility of adding material to existing parts. Furthermore, given the feasibility of deposition while all the machine axes are interpolated simultaneously, complex geometries can be constructed without the need for support structures. Hybrid systems thus represent a viable solution for reducing the time to manufacture complex parts when compared to conventional techniques, as shown in Figure 5.

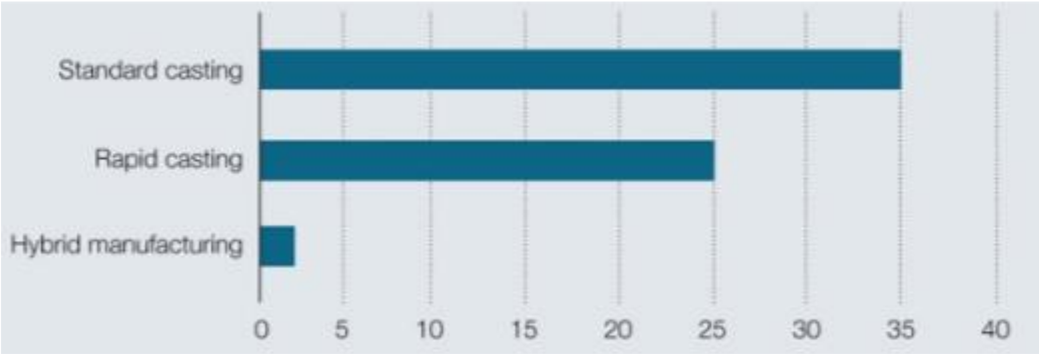


Figure 5. Comparison of production times (in days) of turbines using different manufacturing methods [11]

The combination of additive and subtractive processes in a single "hybrid machine" is especially recommended when low machinability materials are involved, such as heat resistant alloys and high strength materials, which are widely used in the aerospace, automotive or medical industries.

Hybrid machining processes have been used in re-machining (repairing, modifying and reforming) existing components with high added value, as in the case of molds, nozzles or turbine blades. Figure 6 outlines the possible interactions between the additive and subtractive process. The hybridization of the machining process also allows to obtain unique geometries that would not be producible using each process independently, as shown in Figure 7.

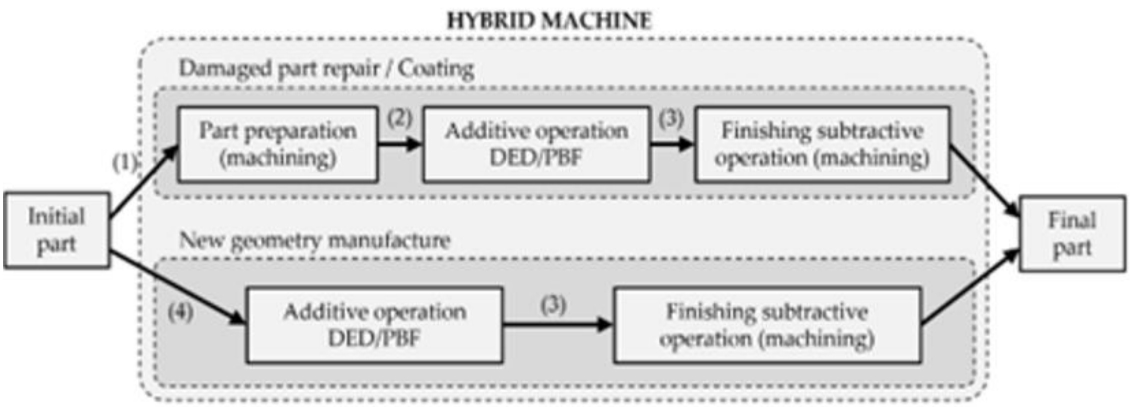


Figure 6. Interactions in the process of a hybrid machine [11]

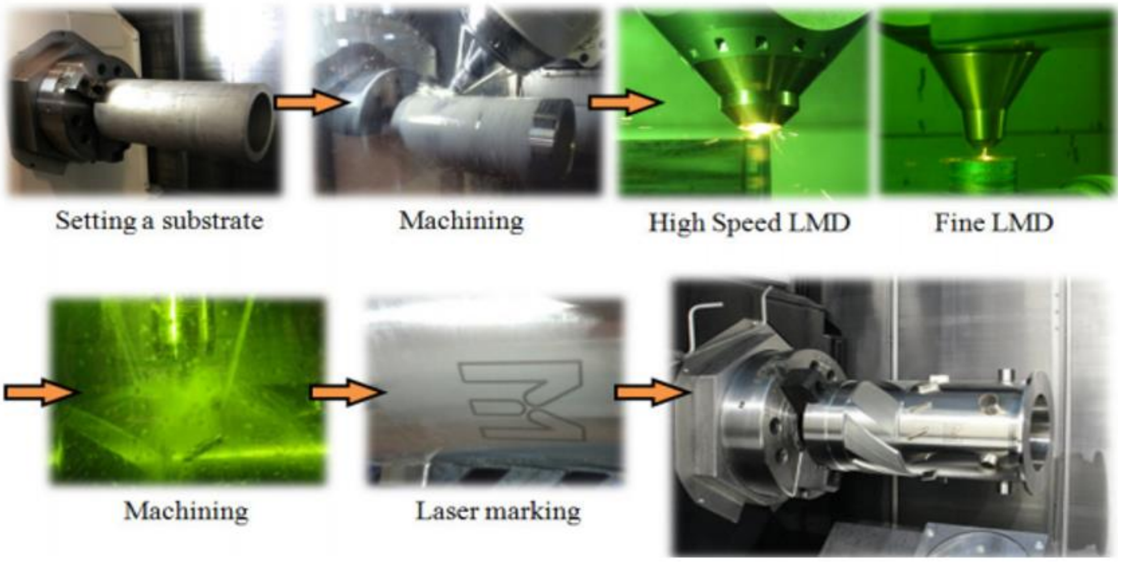


Figure 7. Example of a hybrid manufacturing sequence [12]

2.5.2. Applications of additive and hybrid processes in tooling

Tooling types that are now harvesting the advantages of AM and hybrid processes include:

- moulds, such as plastics injection moulds, die casting moulds, moulds for glass manufacturing and moulds for composite manufacturing;
- dies for stamping, both hot and cold stamping, and extrusion dies;

These applications benefit from using AM or hybrid processes mainly because of:

- the possibility of reducing the amount of materials spent on the tool, using optimization techniques – mainly using generative design to obtain lattice structures and topology optimization.
- the possibility of optimization of the cooling function that is a part of many of the tools mentioned, such as moulds and hot stamping dies, mainly through implementing conformal cooling channels, but also by implementing internal lattice structures.

Some examples of the above items are now going to be presented, based on the available literature.

2.5.3. Material optimization – topological optimization

Cases of topological optimization can be found on plastics injection moulds, stamping dies and others. Asnafi *et al* [13] present examples of production tools for the two above cases. For stamping tools examples of U-bend dies and punches are presented. For the punch geometry studied - Figure 8 - the authors show, through experimental and numerical methods, that there was a weight reduction of 34% for the conventionally designed punch (with lattice structure) and 45% in the case of the topology optimized punch.

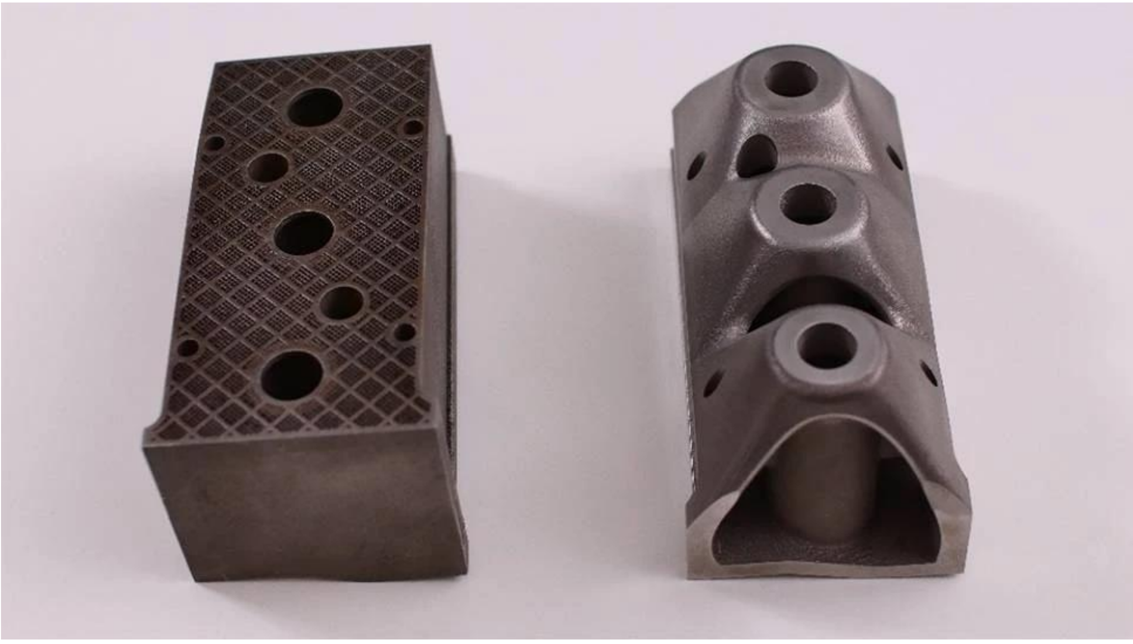


Figure 8. An industrial punch: Conventionally designed and 3D-printed with a honeycomb inner structure (left) and 3D-printed after topology optimization (right). Material = DIN 1.2709 in both cases [14]

A case of a combination of puller / punch for an automotive stamping tool was also presented by Asnafi et al [15]. The part was 3D printed to have an inner lattice structure and thus remove mass. The parts have specific requirements and thus a comparison on how those requirements are met when using different technologies was also presented

(Figure 9). Results of the 3D printed parts are shown on Figure 10. The total manufacturing time was decreased from 8 to 3.7 days by employing the lattice structure optimized part.

CONVENTIONAL PROCESS

Punch
Requirements:
- Hardness (after hardening) = 55 HRC
- Surface roughness in the working area = R_a = 0.8 µm

Material = SS2263 (tempered)
Process:
1: Milling
2: Hardening
3: Wire EDM

Puller
Requirements:
- Hardness (after hardening) = No requirement
- Surface roughness in the working area = R_a = 2-3 µm

Material = SS2172
Process:
1: Milling
2: Wire EDM

3D METAL PRINTING

Punch
Requirements:
- Hardness (after hardening) = 55 HRC
- Surface roughness in the working area = R_a = 0.8 µm

Material = Maraging steel (1.2709)

Puller
Requirements:
- Hardness (after hardening) = No requirement
- Surface roughness in the working area = R_a = 2-3 µm

Material = Maraging steel (1.2709)
Process:
1: 3D printing of punch and puller
2: Post-processing
3: Hardening of the punch
4: Machining of the working area

Figure 9. The requirements set and the materials and manufacturing processes for the conventional and 3D-printed versions of the puller and punch for the C Bow Lower progressive die in Fig. 10. EDM = Electrical Discharge Machining. SS = Swedish Standard. From [15]

Figure 10. The 3D-printed puller & punch in the progressive die. Material = DIN 1.2709. The honeycomb structure has a facade/outer shell thickness of 1.5 mm. Adapted from [15]

2.5.4. Conformal cooling

The same authors present cases for injection moulds [14]. A core and insert part for a plastics injection mould were modified to have their cooling channels conformed to part geometry - Figure**¡Error! No se encuentra el origen de la referencia.**. Results shown a decrease in moulding cycle time, thus resulting in a lower cost per part. This reduction is enough to compensate for the increase in the tooling manufacture costs.

Another example of conformal cooling can be found in dies for hot stamping . The process of hot stamping is used for forming of ultra-high-strength steels and some aluminium alloys, where the plastic deformation phase is performed at high temperature and a quenching phase is employed after forming, to produce the desired properties on the sheets. A critical cooling rate is necessary to obtain the adequate structure on the material, and this entails the need for cooling channels on the dies.

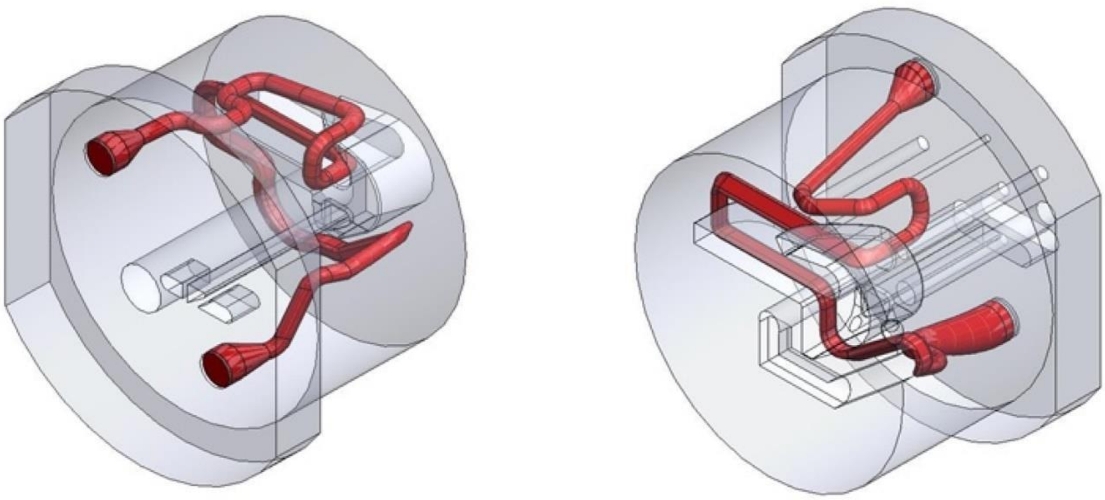


Figure 11. The core/inserts for injection molding optimized by the simulations. Red color = the cooling channels after optimization. Adapted from [15].

Several examples of optimization of cooling in these tools can be found in a the review from Chantzis et al.[16]. An example presented is the work of Cortina et.al [17], where a conformal cooling channel was produced in a hot stamping die through a hybrid process involving an steel block pre-machined to produce part of the cooling channel, which is then closed by LMD -Figure 12.

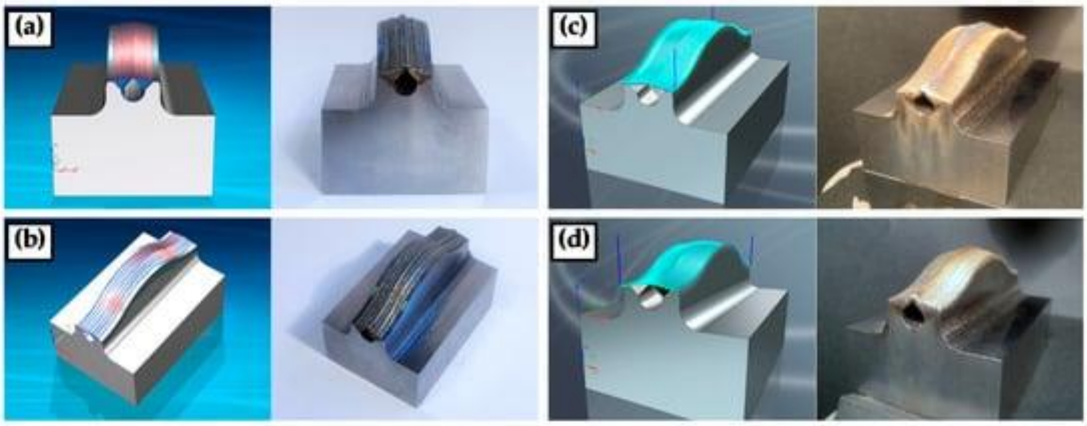


Figure 12. (a) Front; (b) lateral views of the resulting part after LMD; (c) transversal LMD; (d) longitudinal LMD. From [17].

Results show a decrease in maximum temperature on the die, a better distribution of temperature in the tool, which contributed to better part properties and lower cycle times - Figure 13.

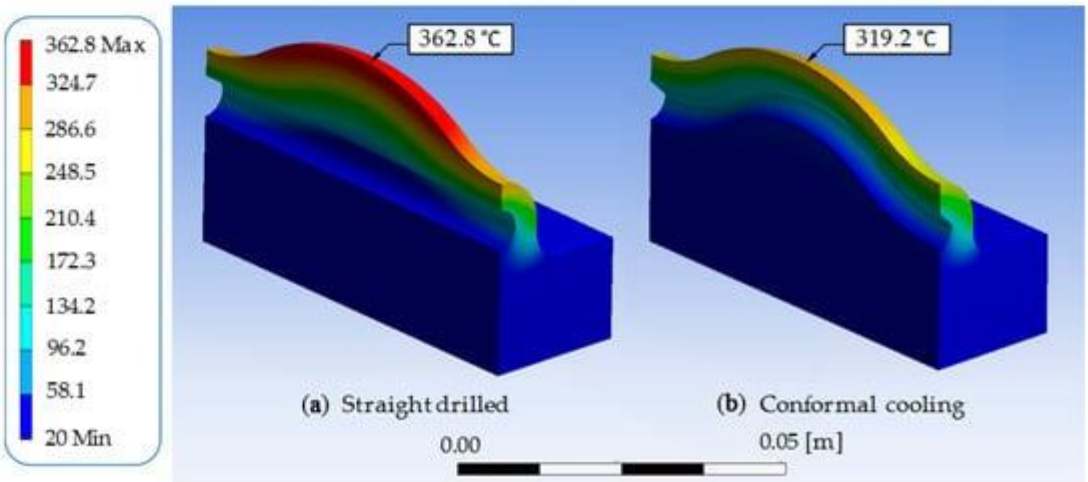


Figure 13. Thermal simulation results of conventional drilled (a) vs. conformal (b) cooling. From [17].

3.AM DEMAND ON TOOLING SECTOR

Based on an in-depth analysis of the sector, the consortium of ADDITOOL project is carrying out a short, medium and long-term study of Metal Additive Manufacturing (MAM) determining, as accurately as possible, the needs of the tooling industry and taking advantage of the maturity of all available technologies.

For this purpose, a survey has been performed as the first step of WP1 *"Identification of needs and definition of cases of application*". The results can be found in the deliverable "*D1.1.1 Diagnosis_Report_of_MAM_in_tooling_sector*" where the main objective was to identify the needs of players in the Metallic Additive Manufacturing (MAM) domain and within the tooling sector.

The survey was targeting both tooling manufacturer and tooling end user. A total of 85 responses was obtained encompassing Portugal, France and Spain. Greater participation in the survey have been found in sector such as Aeronautic, Automotive and Defence. Moreover, great diversity of sectors has also participated, such as Medical, naval, Educational, toys, building sector, mining sector and many others.

Regarding the application of MAM but also the usage of the tooling in each company, it has been observed more interest in outsourcing manufacturing service than acquiring equipment. Also, more interest in manufacturing a specific part rather than to repair or to add new functionality to a tool. Moreover, most common types of manufactured (provider) or used (end user) tooling according to survey results were assembly, moulds for plastic, and machining tools.

In relation with Additive Manufacturing Technologies, Material extrusion and Powder Bed fusion were presented as the most demanded technologies.

Nevertheless, there is a STRONG BELIEF in this new manufacturing process, since more than 96% of respondents recommends the TOOLING INDUSTRY SHOULD INVEST in this technology.

In terms of obstacles which inhibit wider deployment of MAM, initial investment has been selected as the first obstacle, followed by the costs of produced parts.

Again, comparing with conventional technologies, high cost of equipment and raw material have been chosen as the weakest factor of using MAM.

Regarding MAM tooling challenges, certification and cost reduction have been considered more challenging than design or manufacturing. On the other hand, freedom in design has been selected as the biggest advantage of using MAM over conventional technologies.

In terms of developing knowledge, collaboration with an external partner has been considered as the most adequate training for developing skills followed by specific short duration courses.

Most of the surveyed companies do not have plans for hiring MAM staff (or do not know).

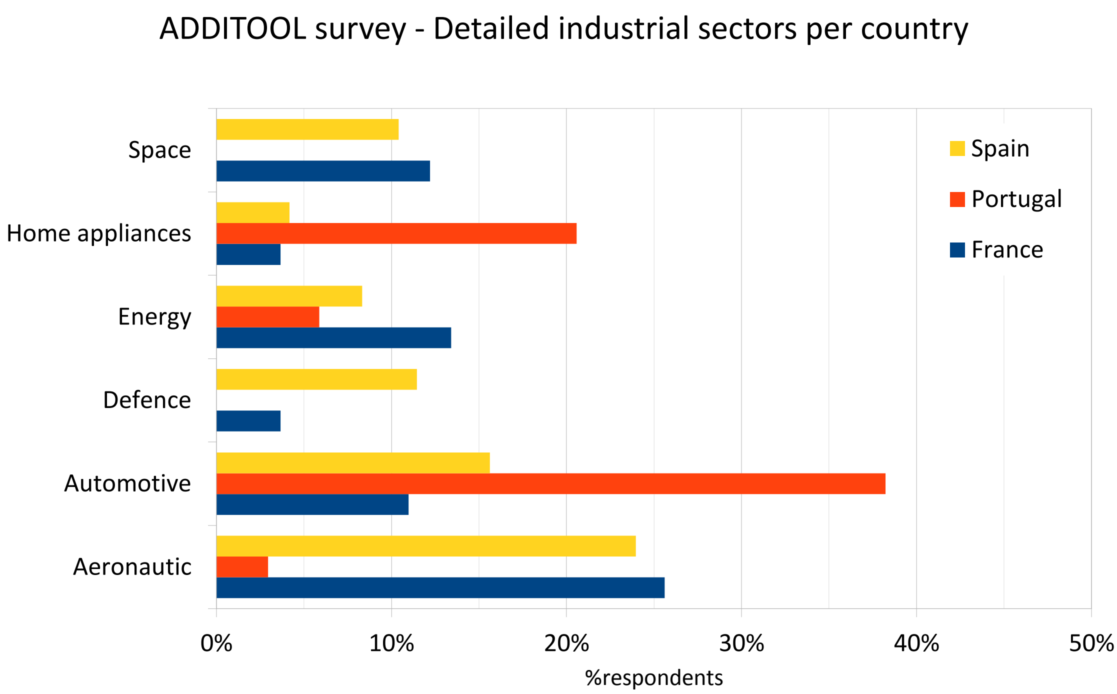
4.IDENTIFICATION OF OPPORTUNITIES

The purpose of this chapter is to identify opportunities for future development of MAM technologies in the tooling sector following the results of the survey. To provide a base for the future case studies selection, it is necessary to gather inputs on specific industrial needs in each of the countries.

4.1. Results breakdown per country

4.1.1. Detailed industrial sectors per country

Regarding industrial sectors per country, the survey has shown good diversity with higher participation of aeronautic and Space industry in France and Spain, and Automotive and home appliances in Portugal.



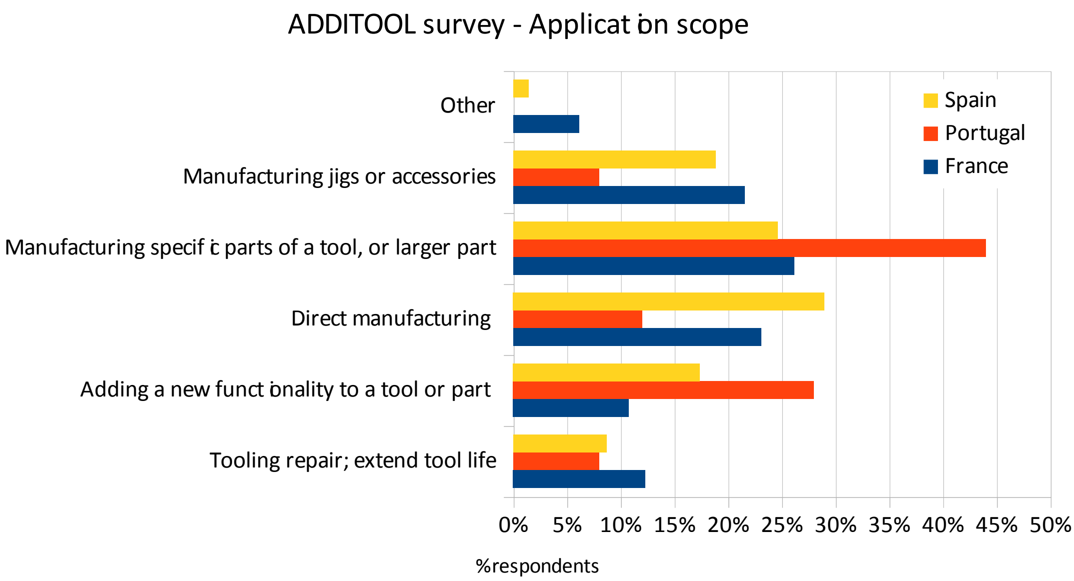
Detailing the tooling types for the above sectors, it was found that assembly, moulds for plastic and machining tool have been selected as the most common types of tooling, across the three countries. If we consider the results of this parameter per country, we can observe:

- moulds for plastics represent the vast majority of tool types used / manufactured by Portuguese respondents;

- for Spanish and French respondents, drilling tools and dies for sheet metal forming also gather a significant percentage of responses.

4.1.2. Detailed application scope for MAM technologies

About the application scope for MAM technologies, the three surveyed countries have selected "Manufacturing a specific part of a tool, or a full part itself" as the main objective.



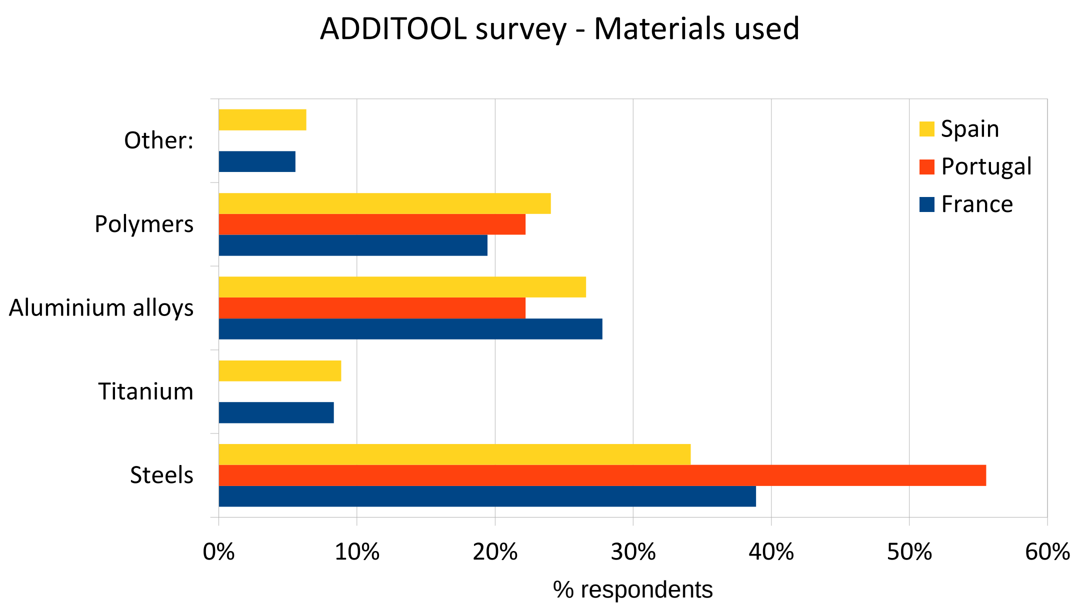
If we consider the results of this parameter per country, we can observe:

- Spanish and French respondents also refer "Manufacturing jigs or accessories" as a relevant applications

- Portuguese respondents also selected "Adding a new functionality to a tool or part" as a significant application.

4.1.3. Detailed materials and AM technologies

Concerning the AM materials and technologies currently in use, the survey respondents generally indicate that Steel is the most common material, followed by Aluminium. Currently used AM technologies are mainly FDM (30%) and PBF (15%).



4.2. Opportunities identification

The detailed analysis of the survey outcomes in each country establishes the base for proposing specific opportunities for technological development of MAM technologies in each country. These are proposed next.

4.2.1. Spain

Spanish industrial tooling manufacturers currently produce machining tools, assembly tools, drilling tools and moulds for plastic, destined to Aeronautic, Automotive and Space industries. Currently these industries are interested in using AM technologies for manufacturing a specific part of a tool or a full part itself, and Manufacturing jigs or accessories.

For Spanish companies, opportunities may be on:

- seeking to develop tool repair (using large-scale AM technologies and/or hybrid technologies)

- seeking to optimize technologies already in place
- seeking to extend the sectors less represented - moulds for die casting, forging dies...

4.2.2. France

French industrial tooling manufacturers currently produce machining tools, assembly tools, drilling tools, moulds for plastic, and dies for Sheet metal forming, destined to Aeronautic, Automotive, Energy, and Space industries. Currently these industries are interested in using AM technologies for manufacturing a specific part of a tool or a full part itself, and Manufacturing jigs or accessories.

For French companies, opportunities may be on:

- seeking to develop tool repair and adding functionality to a tool, using large-scale AM technologies and/or hybrid technologies
- seeking to optimize technologies already in place
- seeking to extend the sectors less represented - moulds for die casting, forging dies...

4.2.3. Portugal

Portuguese industrial tooling manufacturers currently produce mainly moulds for plastic, either destined to automotive or home appliances industries. Currently these industries are interested in using AM technologies used for mould inserts or mould added functionality.

For Portuguese companies, opportunities may be on:

- seeking to develop tool repair strategies (using large-scale AM technologies and/or hybrid technologies) or the manufacturing of jigs and accessories.
- seeking to optimize technologies already in place
- seeking to extend the sectors less represented - assembly tools, machining tools.

4.3. Case studies selection

For selecting the set of case studies to be addressed during WP2, a strategy is now proposed. Each project partner proposes case studies based on the outcomes of the survey – see the main potential areas above - such as:

- At least 1 case study addresses one of the main areas / technologies / scales (tool/feature size) identified. This adds to a total of 3 case studies
- Additional case studies can address secondary / less explored / less developed applications identified above

The 4th case study proposal is selected having into account the full spectrum of technologies / application areas / scales covered by all case studies and considered to provide the highest potential for impact of the project outcomes.

Hence, a scoring table is proposed, to assist on the selection of the best solution for the set of case studies:

Case study	Materials	Score	Technologies	Score	Scale	Sector	TRL
PT1 – mould inserts	Steels	1	SLM, Milling	2	S	Auto, HA	5 to 6
PT2 – moulds for glass	Steels, Nickel	2	SLM, DED, Milling	3	S	Food	3 to 4
ES1							
ES2							
ES3							
FR1							
FR2							
FR3							

KEY: Scale: S – small, M – medium, L – large | TRL – technology readiness leve | Sectors: Auto – automotive; HA – home appliances, Food – Food and beverage, Aero – Aeronautic, Sp – Space, O&G – Oil & gas, AgI–Agricultural-industry, EN – Energy, Def – Defence, O – other

Project partners can contact regional associated partners / local companies to propose the most relevant case studies to be included in candidates list. The criteria for the selection of the appropriate set of case studies should be discussed and defined by all associated partners of the project. After all proposals are gathered, the choice of the set of final 4 case studies, based on the criteria defined above, can be completed.

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