Time Horizon

Short-term goals (2–3 years):

- **Autonomous solutions for real-time optimization of productivity and process quality**—These solutions should not be considered only at individual machining process level. Instead, it is necessary to develop rules and logics at machine and manufacturing cell level.

Medium-term goals (4–6 years):

- **Solutions to reduce the environmental impact of manufacturing**—These solutions must be meant to act both on the process side and on the automation side, at machine level and at cell level.
- **Generative design**—Aimed to develop approaches that may turn the design of physical chemical properties into methods available in CAD CAM for the mechanical designer and establish specifications that can be transferred to the manufacturing process.
- **Digital Twin models of tools, machining processes and processing machines—** In the medium term, new models must be studied and developed for CAD, CAM and simulation platforms, to ensure the formalization of knowledge and calculation speed.

Medium-long term objectives (5–10 years).

- **Multifunctional joining techniques**—The improvement of the characteristics of multifunctional joints is being researched and, in order to be truly applicable in the industrial field, it requires the development and fine-tuning of new processes that can guarantee an optimal balance of the priorities of the various materials.
- **Process control through artificial intelligence systems**—selection and optimized control of process parameters during AI-supported machining.
- **Adaptive and resilient processes** to comply with this definition, processes must be able to adapt the manufacturing cycle of products based on the deviations of the characteristics of materials and incoming parts. Furthermore, tools and methodologies must be developed to quickly adapt processes to the new productions.

5 PRI5.4 Manufacturing Processes Using Hybrid Technologies

Developing production systems to support customization is a goal of the transition to Industry 4.0 at national and international level (A graphical method for performance mapping of machines & milling tools; Agubra et al., 2016). This goal can be achieved by developing flexible, productive solutions that can process the new materials available on the market. Thanks to research and technological development, many conventional and unconventional manufacturing processes are now available for a highly efficient machining of traditional and innovative materials. The combination and integration of these processes to create a hybrid production system is a fundamental step to drive further improvements in process efficiency and greater flexibility. Hybrid manufacturing processes are based on a controlled interaction of several processes during the same machining procedure. These processes have different energy sources, tools and process parameters (AMFG—The Additive Manufacturing Landscape, 2020). This integration can help obtain improved performance, i.e. better machining of materials and less friction, and achieve high levels of flexibility by promptly alternating multiple technologies within the same manufacturing process. This can already be seen in the additive-subtractive hybrid machines recently launched on the market (Arias-Rosales).

The integration of different technologies poses challenges at design and process management level. It will be necessary not only to identify the optimal solutions for hybridization, pinpointing groups of technologies that can lead to concrete benefits thanks to a thorough integration, but also to develop solutions and approaches for an efficient use of hybrid technologies, whether in terms of guidelines for redesigning components and work cycles or in terms of software for constant exchange of information between integrated processes (Manufuture 2030; Armendia et al., 2019).

These systems should allow companies to reduce manufacturing cycle times and manufacturing cycle setup times, significantly increasing production flexibility. The introduction of new multi-materials makes it possible to obtain products with better physical–mechanical characteristics than current solutions. Furthermore, an increase in productivity is expected thanks to the support of multiple technologies/energy sources. Processes will be faster and cheaper and material waste will be contained by adopting technologies that can reduce the geometric constraints of current solutions (e.g.: additive–subtractive hybrid solutions).

The goal of this research and innovation priority is to study and develop advanced hybrid solutions and in particular:

- **Hybrid machines** that can use different technologies both sequentially and simultaneously and improve the performance of a manufacturing process and its manufacturing flexibility. Furthermore, new solutions should be developed, introducing multisensory approaches to control materials and product in line.
- **Hybrid solutions for AM:** Integration of additive technologies and conventional technologies, for a greater flexibility in production planning by containing lead times, and in the definition of a component's geometries. These technologies also promote the creation of multi-material and/or fiber-reinforced hybrid components.
- **Design of hybrid processes/tools** to improve machining yield and increase process capacity, by exploiting multiple technologies at the same time (for example drilling and ultrasound, laser and plastic deformation, forming and joining processes, differentiated functionalization of the different materials in a product).
- **Hybridization strategies through the use of mechanical and thermal processes** or conditioning technologies (lubrication, refrigeration) for the material being processed and the tools.

- **Combination of traditional and micro-scale machining** in an integrated machine that guarantees an improvement in cycle times (i.e. time required to move the component from one station to another) and component quality (no repositioning).

Interaction with Other Action Lines

- Interaction with LI1 (Systems for customized production) since the integration of multiple processes in a single manufacturing system will make it possible to develop machines that can support Mass Customization, not only because of an increase in flexibility, but also because of the introduction of new (multi) materials that can more easily meet the customer's needs.
- Interaction with LI4 (Systems for high efficiency manufacturing) since the integration of technologies will aim to improve the efficiency of the process thanks to the development of new approaches that increase a material's workability, lubrication and machining rate.

Time Horizon

Short-term goals (2–3 years):

- **Hybrid solutions for AM**: improvements regarding process monitoring, development of guidelines for their efficient use and greater flexibility in changing materials.
- **Hybridization strategies through the use of mechanical and thermal processes** (2–3 years): improvement of processing efficiency to increase the number of possible applications (e.g.: Laser Assisted Machining).

Medium-term goals (4–6 years):

- **Hybrid process/tool design** (4–6 years): the development of highly integrated manufacturing systems consisting of 2 or more technologies requires the design of new machines and the development of control systems and guidelines for its efficient use.
- **Combination of traditional and micro scale machining** (4–6 years): the application of hybrid technologies to the micro world will reduce the components' manufacturing times in rapidly growing sectors such as medical devices.

6 PRI5.5. Manufacturing and Machining Processes for Innovative Materials

The European strategy towards circular economy (waste elimination) implies that materials for 500 Mt/year could be re-injected into the economic system. Therefore, materials innovation will be oriented towards greater sustainability in terms of durability, environmental sustainability, the reusing/recycling possibility, zero/low CO_2 emissions. The replacement of metals with polymers is already a reality thanks to injection processes for the manufacturing of gears, levers, pulleys, for example in food packaging. Innovative design is already proposing materials obtained from completely natural raw materials (bio-based and biodegradable packaging), such as "plastics" from algae. Organic alternatives such as bamboo, mushrooms and wheat straw are already being used in place of traditional oil and plastic-based packaging.

Innovation in materials requires guaranteed performance, to be implemented in terms of multifunctionality and diversification of application areas, because of the improved performance (for example of composites) with respect to the new geometries/architectures resulting from the application of lightening, miniaturization and hybridization.

The use of materials can be improved from as early as the combined product/material design phase, by developing databases and software tools that include material, process, product performance and life cycle changes, by enhancing modeling tools and advanced characterization (generative design). (Arias-Rosales; Armendia et al., 2019) The development of new materials (light, high-performance, secondary materials) requires the study and development of many technologies, processes and capital assets.

The objectives of this priority for the coming years refer to:

- **Technologies for manufacturing based on innovative materials**, with high mechanical and functional characteristics such as CO2 capture materials, membranes and filter systems, catalysts, NOx depletion coatings, waste materials, for the water and gas effluents treatment materials, new polymers and composites including from organic waste, biocompatible materials, lighter materials, recycled materials from other machining processes (second life materials);
- **Technologies for manufacturing energy products based on high performance materials** such as metal alloys, ceramics and coatings for high temperatures, structural materials for advanced wind technologies, functional materials for photovoltaic and solar thermal systems, of energy accumulation materials, thermal insulation and electricity/heat storage materials (Bourell et al., 2005; Byrne et al., 2018; Cainelli et al., 2020; BIT II – La Bioeconomia in Italia).
- **Technologies for manufacturing products based on the use of nanomaterials** that allow the functionalization/nano-structuring of surfaces to give, for example, antimicrobial, antiviral, "anti-fouling", self-cleaning properties, especially focusing on manufacturing safety and the use of nano-powders.
- **Innovation of processes** for manufacturing complex high-value materials increasing their efficiency (in terms of energy consumption, waste reduction, reduction of the use of non-renewable raw materials)
- **Technologies for manufacturing materials for high-risk applications**, such as materials to operate in specific environmental conditions, explosive atmospheres, biological and chemical risks.
- **New processes for manufacturing composite materials on a large scale** as well as tools to process them (wear resistance, low cost, flexibility).

Interaction with Other Intervention Lines

- Integration with LI3 and LI4 with regard to the improvement of monitoring/diagnostic tools, which is possible thanks to materials for new sensors, actuators, wireless systems,
- Integration with LI3 also with regard to the impact of the processing of new materials on the workers' health risks;
- Generative design is a topic shared with LI7, for a greater integration of the materials' data in computing systems' libraries.
- Integration with LI4 with regard to the technologies for the production of energy materials. The aim is to achieve a large mass production that is competitive on the global scene and yet meets the safety and environmental sustainability standards of EU regulations.

Time Horizon

Short-term goals (2–3 years):

- Manufacturing of structural and functional materials: this goal, which is currently consolidated at laboratory level, will be effectively introduced into the manufacturing system in the coming years.

Medium-term goals (4–6 years):

- Technologies for the use of nano-materials: the technologies that will allow industrial production in the next five years will have to be developed in the short and medium term.

Long-term goals (7–10 years).

- Production of energy materials with particular reference to the segments of the battery value chain, to achieve the set goals by 2030.
- Development of new processes for the manufacturing of composite materials on a large scale: this goal is strongly correlated to the evolution of technological production processes (from traditional to innovative ones such as additive manufacturing) and is currently in a mature phase as regards manufacturing of composite materials, but still ongoing for large-scale production.

7 PRI5.6. Micro-Scale Processes, Products and Functionalities

In recent decades, a strong trend has emerged towards the miniaturization of devices, to extend their use to contexts with space and weight limitations. The electronic field, with MEMS, was the pioneer of this breakthrough towards miniaturization, first with laptops and then with smartphones. The coming of microengineering, in addition to microelectronics, has generated new product and process strategies that are becoming significantly widespread in the aerospace, automotive and, above all, biomedical industries. The latter, in particular, represents the real next frontier of micro devices development. In fact, applications such as lab-on-chips and microfluidic devices in general, for home care and self-diagnosis, have become attractive development areas for the scientific community and the industrial world.

In the field of micromachining, two different approaches can be identified, namely one that specifically focuses on the creation of micro components and one that deals with developing micro functionalities on macro products. These two approaches often involve, in different ways, main micro-processing techniques such as micro EDM, laser micro-processing, micro-milling, injection micro-molding, surface micro structuring. In other cases, however, they all contribute, thanks to an interdisciplinary approach, to the development of very complex devices with a massive impact in terms of diffusion.

The "micro factory" has become the new manufacturing standard, and it focuses on the realization of micro components and micro devices. The production of micro parts often requires special manufacturing, handling and assembly environments, such as clean rooms or vacuum chambers. A prerequisite for both the micro-factory and the (macro) factory, is the achievement of complete process integration. The manufacturing of micro parts can, in fact, be facilitated if different processes (or process phases) are performed with only one positioning, in order to contain machining tolerances, with micrometric or even sub-micrometric precision. A new concept of factory is being defined, as a result of the high cost of the devices and equipment used in microfabrication, and the high technological competence required, namely the concept of a widespread (micro) factory, in which the various parts of the equipment are available in different places, towns or even regions. This approach distributes the costs of purchasing and operating equipment, but it also requires planning to optimize the transfer of components or semi-finished products (sometimes in considerable volumes) from one place to another. Thus, "design for micro-manufacturing" and "design for micro-assembly" are no longer alternative, but strongly interconnected approaches. An aspect that is positively affected by this miniaturization process is certainly logistics. Indeed, moving these micro parts is very simple and very economical as their small size makes them considerably easier to be packed and transported safely, while also ensuring the management of large volumes.

Therefore, the essential goals for the next few years, in order to bring the micro manufacturing sector to an important level of feasibility, are:

- **New approaches focused on the reliability of micromachining processes**: a topic in great demand by the European Community is "reliability", since the medium-term goal is to reach industrial production level for micro-base devices and/or components, through the study and development of new approaches that improve the reliability of micromachining and surface functionalization and structuring;
- **New approaches for the geometric characterization of products and functionalities at micro level**: this is one of the most critical aspects of micro manufacturing because the typical "macro" approaches do not work when it comes to the characterization of a micro product or functionality due to technical limitations,

because of its small size and the risk of damaging micro components. It is therefore necessary to study and develop new inspection technologies, new approaches and methodologies to support the geometric and surface characterization of micro products.

- **Methodologies and approaches for simulating micro processes:** simulation is fundamental for virtualization of processes in order to minimize errors and reduce manufacturing costs. Several efforts have been put in recent years in the simulation of micro processes. This has highlighted the need for new approaches to support processes such as micro injection molding and laser-material iteration, with high-brightness sources as well as ultra-short pulses, micro electro-erosion and micro milling.
- **New micro factory models**: the current approach to micromachining as dedicated to individual independent processes need to be overcome. In particular, the migration to "micro factories" needs to be supported by integrating the different micromachining processes and minimizing mistakes, ensuring high production quality also through the distributed micro factory concept.
- **Technologies and systems for assembly at a micro geometric level**: this is an aspect of great scientific interest which, however, still has a very low TRL. The handling of micro components presents several criticalities. This involves the need to study new technologies and systems for assembly operations such as the gripping of a micro component, its correct orientation and its release.

Interaction with Other Action Lines

- In view of the research priorities expressed by LI2, micro technologies, especially in the manufacturing of parts made with innovative materials, can be considered highly sustainable given the small size of the devices and the consequent lower use of materials.
- The concept of micro factory requires interaction at a macro level with LI4, LI6.

Time Horizon

Medium-term goals (4–6 years):

- **Reliability of micromachining processes.**
- **Geometric characterization of products and functionalities at micro level:** reaching a level of geometric characterization for micro components, as is already available for macro components, is still an open challenge. Eventually, however some light begins to be shed on the goal. The great scientific efforts made over the last few years to identify characterization criteria for the micro sector are moving in the right direction. The real challenge is implementing vision systems also for the control of micro components during the manufacturing phase
- **Simulation of micromachining processes:** the simulation of micro processes is very complex since it often presupposes the use of software developed for conventional processes, the reference models of which must therefore be adapted. The main difficulty lies in the fact that anything considered negligible at macro

level takes on considerable importance in the micro field. Let us think, for example, of the Van der Walls forces, the surface tension rather than the adhesion coefficient.

Long-term goals (7–10 years).

- **Technologies and systems for handling and assembly at micro geometric level:** The handling of micro-components, their correct orientation and release are very complex issues, and they still require a lot of research efforts combined with the need to rethink the devices' design with a view to minimizing as much as possible both handling and assembly phases.
- **Integration of micro processes towards the concept of micro-factories**: this is the real challenge for the future, i.e. the integration of various micro-machining processes, at present still often used independently.

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