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STUDY ON THE INTEGRATION OF POLYAMIDE IN AUTOMATED PRODUCTION SYSTEMS

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Abstract: The paper analyses how polyamide is integrated into modern automated production systems, with a focus on industrial applications such as CNC machining, 3D printing, and robotics. The advantages of using polyamide, especially polyamide 6 with carbon fiber, for manufacturing lightweight, wear-resistant, and chemically stable components are highlighted. The study also explores the role of IoT platforms and intelligent control systems in optimizing industrial processes, emphasizing current industry trends in production automation and digitalization.

Key words: Polyamide, automated production, CNC, 3D printing, carbon fiber, IoT, intelligent control, advanced machining.

1. INTRODUCTION

One of the most promising fields for the use of polyamide is its integration into automated production systems, which include processes such as additive manufacturing, CNC machining, and industrial robotics. These systems enable mass production of complex polyamide parts, thereby increasing productivity and reducing overall production costs.

2. ROBOT-ASSISTED PRODUCTION SYSTEMS

Industrial robots are a key component of modern manufacturing, being used for complex operations such as assembly, welding, and material handling. Polyamide is used for manufacturing essential parts of industrial robots, due to its mechanical strength and lightweight properties [10].

2.1 Application of Carbon Fiber in Robotic Arms

In modern industry, robotic arms with multiple degrees of freedom are essential for production and industrial activities. These arms are often made from metallic materials, which,

although durable, have limitations in terms of weight and resistance to corrosion. In contrast, carbon fiber composite materials have gained popularity due to their superior characteristics, such as low density (around 1.7 g/cm^3), which is about half that of aluminum, and excellent rigidity and vibration resistance.

Carbon fiber offers a significant advantage in designing lightweight structures, while also providing great design freedom and the ability to create integrated, compact, and flexible components. A carbon fiber robotic arm is more rigid and stable, with an almost zero coefficient of thermal expansion, meaning it will not deform due to temperature changes. It also has excellent resistance to corrosion and environmental influences, being immune to organic solvents, acids, bases, and salts.

However, using carbon fiber for robotic arms entails higher costs and technical challenges in the manufacturing process. Despite these, technological advances and improvements in production processes, such as those implemented by leading companies, help reduce costs and increase production efficiency, making carbon fiber an increasingly viable choice for advanced industrial applications.

2.2 Polyamide 6 with Carbon Fiber for Robotic Arms

Polyamide 6 with carbon fiber is used in the construction of robotic arms due to its remarkable characteristics, which offer superior performance in various industrial applications. These include (according to [11]):

- *Superior chemical stability:* the material retains its integrity when exposed to chemicals, making it ideal for industrial environments.
- *Low weight:* polyamide 6 with carbon fiber helps reduce the weight of the robotic arm, improving mobility and operational efficiency.
- *Resistance to chemicals:* it is unaffected by chemicals, ensuring increased durability in aggressive environments.
- *Fatigue resistance:* comparable to traditional materials such as cast iron and aluminum alloys, polyamide 6 with carbon fiber offers excellent resistance to fatigue and repeated mechanical stress.

In Figure 1 [12], which illustrates a robotic arm, the benefits of these properties can be observed. The arm, made from polyamide 6 with carbon fiber, features a lightweight yet durable structure, capable of withstanding intense and varied working conditions.



Fig. 1. Robotic Arm Made of PA6 [12]

Polyamide can also be used in the manufacturing of transmission components (polyamide gears and bearings are ideal for the motion systems of robots) or handling systems (polyamide provides an optimal combination of flexibility and durability, making it suitable for gripping devices).

3. INTELLIGENT CONTROL OF THE PRODUCTION PROCESS

Automated control systems allow real-time monitoring and adjustment of processing parameters. These technologies are used to reduce errors, improve part quality, and minimize material waste.

Examples of control systems:

- **Smart sensors:** Monitor temperatures, pressures, and rotation speeds during CNC machining and injection molding.

Temperature sensors with threaded resistance probes are designed for measuring temperatures in liquids and gases, ensuring reliable process connection under both negative and positive pressure conditions. These are used in applications such as heating, cooling, and industrial automation systems. Figure 2 [11] illustrates an example of a temperature probe with a cable, the ET211 model, which can be used in these applications.

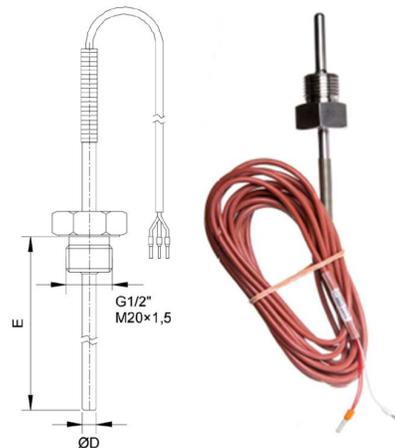


Fig. 2. Temperature probe with cable, model ET211. [13]

Depending on the application requirements, several additional features are available, such as: RTD platinum sensing elements with specific nominal resistance and accuracy class for temperatures up to $+500^{\circ}\text{C}$, standard thermistors, protective tubes in various sizes with threaded fittings, connection cables for dry or wet conditions, and flexible stainless steel armature. The standard version includes a Pt100 RTD sensor class B, with a measurement range from -50°C to $+250^{\circ}\text{C}$, a protective tube $\text{Ø}6$ mm

with a G1/2 thread, and 3 meters of silicone-insulated cable with 3 wires (according to [13]).

- **IoT platforms:** Allow access to real-time production data for process analysis and optimization [2].

The term "Internet of Things" (IoT) refers to a network of intelligent physical objects capable of communicating and sharing information about their internal state and the surrounding environment. These objects integrate technologies that allow them to detect, collect, and transmit real-time data. The rapid development of IoT has the potential to significantly transform industry, the environment, and people's lifestyles [5].

It is estimated that by 2030, the number of interconnected smart devices could reach around 200 billion. These include both common objects, such as phones, tablets, smart TVs, and household appliances, as well as advanced devices for monitoring health, water or air quality, and for supervising and controlling complex industrial equipment or goods transported in containers [7].

The increased interest in this field in recent years is justified by the considerable potential to apply IoT solutions in various practical areas, generating significant benefits.

Figure 3 illustrates the architecture (along with the functional links and specific interactions) for two types of IoT platforms: (a) a cloud-distributed platform and (b) a centralized or local platform (according to [9]).

As an example of best practices, the paper [9] presents the results of a detailed analysis conducted by experts from the universities of Helsinki, Oulu, and Jyväskylä. The study was conducted on a sample of 39 IoT platforms available on the market, aimed at supporting the development of Finland's national IoT program [4]. The evaluation criteria used include:

- **Compatibility with IoT devices:** Platforms that require a proprietary gateway for integrating IoT devices are less flexible, as they depend on the platform providers for adopting new protocols and expanding support for a wide range of heterogeneous devices.
- **Platform implementation model:** Most IoT platforms operate in the cloud, either as

Platform as a Service (PaaS) or Software as a Service (SaaS). In the PaaS model, platforms provide services such as data storage, device management, connectivity, backup mechanisms, and online technical support. On the other hand, SaaS focuses on connectivity and data integration, leveraging the capabilities offered by cloud computing infrastructure.

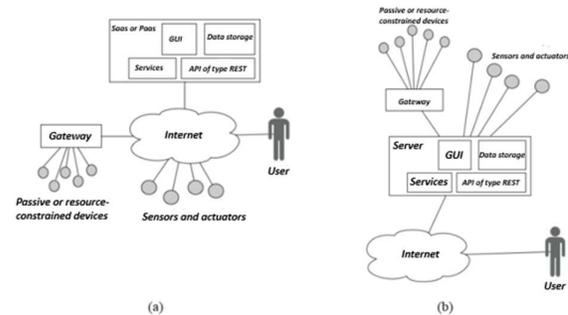


Fig. 3. The interaction between the user, smart devices, and IoT platforms in the architecture (a) cloud-based and (b) centralized.

4. CNC MACHINING PROCESS AUTOMATION

The integration of polyamide in CNC machining processes has been accelerated by the adoption of smart machines that use AI algorithms to automatically adjust machining parameters. This technology enables the rapid and precise manufacturing of customized parts with minimal human intervention [6].

Benefits:

- Increased productivity by reducing working time.
- Reduced material waste by optimizing the cutting process.
- Manufacture of complex parts with strict tolerances.

CNC automation represents the implementation of computerized systems to control and manage the tools and processes used in machining. It involves the use of computer numerical control (CNC) technology to ensure precise and repeatable movement of tools and workpieces. Through advanced software, sensors, and robotic systems, CNC automation manages and optimizes key aspects of the

process, such as tool path tracing, automatic tool changes, part handling, and quality monitoring.

CNC technology has brought a major change to the manufacturing industry, significantly increasing productivity, accuracy, and efficiency in machining processes. It also facilitates machining operations without continuous supervision, known as "lights-out" operations. This enables the manufacture of complex parts with high precision, minimizes human errors, and improves resource utilization.



Fig. 4. Automated CNC milling process [15]

5. 3D PRINTING IN AUTOMATED MANUFACTURING

3D printing technology is one of the most innovative production methods, enabling the automated fabrication of parts without the need for manual intervention. 3D printing systems are integrated into smart factories to continuously produce parts made of polyamide.

Examples of industrial applications:

- **Automotive industry:** Manufacturing of interior panels and engine mounts.

In figures 5 and 6, a compact control device (RF Mini) can be seen, designed to facilitate the use of secondary vehicle functions, such as activating the horn or operating the windshield wipers. [3] This device is made from Onyx material, using 3D printing technology on a Markforged printer.



Fig. 5. Custom manual control device 3D printed [3]



Fig. 6. Custom manual control device [3]

- **Aerospace industry:** Manufacturing of structural elements for airplanes and satellites.

Figure 7 [17] illustrates the 3D scanning process, which is used to create a digital model of a complex physical object, such as a front section of the fuselage. This technology then enables the 3D printing of customized and unique models.



Fig. 7. The front section of the fuselage[17]

- **Medical industry:** Manufacturing of custom prosthetics and bone implants [8].

In figure 8 [16], a medical instrument is illustrated, used in the case of a fracture. Surgical instruments must be biocompatible and capable of being sterilized with steam at 134°C. [3]



Fig. 8. Medical instrument used in the case of a fracture, manufactured through SLS (Selective Laser Sintering) [16]

6. CONCLUSIONS

The integration of polyamide, particularly polyamide 6 with carbon fiber, into automated production systems highlights a clear direction towards streamlining industrial processes through the use of advanced materials. The excellent mechanical properties, low weight, and chemical resistance make this polyamide a versatile material, ideal for applications in robotics, CNC machining, and 3D printing.

By using IoT platforms and intelligent control systems, industrial processes become more predictable, reliable, and adaptable to the demands of the modern market. CNC machining automation and advancements in additive manufacturing allow for the rapid and precise production of customized components, reducing human errors and resource consumption.

Thus, polyamide – supported by new technologies – proves its value as a key material in the context of Industry 4.0, contributing to the development of sustainable, high-performance solutions aimed at the future of smart manufacturing.

To fully exploit the potential of polyamide in automated production, intensifying research and development activities is necessary, particularly in combining it with other composite materials to achieve improved performance. Expanding the industrial applications of polyamide to emerging fields such as renewable energy, medical robotics, and automated micro-manufacturing is recommended, where its properties can provide significant benefits.

Another important direction is the advanced integration of IoT technologies and artificial intelligence into manufacturing processes, enabling self-optimization of processing parameters and the implementation of predictive

maintenance systems. At the same time, comparative studies are needed to highlight the advantages and limitations of polyamide compared to other technopolymers, depending on the specific application.

Lastly, continuous training of specialists in advanced materials and smart technologies is essential, through active partnerships between academia and the industry. In an industrial context dominated by digitalization and sustainability, polyamide is on track to become a key material in the construction of an efficient, flexible, and future-adapted production.

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Studiu privind integrarea poliamidei în sistemele de producție automatizate

Rezumat: Lucrarea analizează modul în care este integrată poliamida în sistemele moderne de producție automatizate, cu accent pe aplicații industriale precum prelucrarea CNC, imprimarea 3D și robotică. Sunt evidențiate avantajele utilizării poliamidei, în special a poliamidei 6 cu fibră de carbon, la realizarea de componente ușoare, rezistente la uzură și stabile chimic. Studiul explorează și rolul platformelor IoT și al sistemelor inteligente de control în optimizarea proceselor industriale, subliniind tendințele actuale din industrie în ceea ce privește automatizarea și digitalizarea producției.

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