Industry 4.0
Part I. Selected applications in processing of polymer materials

Mariusz Oleksy[1), *)], Grzegorz Budzik[2)], Agnieszka Sanocka-Zajdel[3)], Andrzej Paszkiewicz[4)], Marek Bolanowski[4)], Rafał Oliwa[1)], Łukasz Mazur[5)]

DOI: dx.doi.org/10.14314/polimery.2018.7.7

Abstract: Examples of applications of the Industry 4.0 concept in manufacturing operations connected with processing of polymer materials were presented. Implementation of Industry 4.0 structure aims at increasing the speed of manufacturing with simultaneous decrease in the number of defective products. Such results are enabled by the use of integrated information systems coupled with automated manufacturing and quality control processes. On the basis of literature and own experience, it was found that the processing industry requires the use of such integrated systems, and further improvement of competitiveness will be difficult to achieve without implementing the developed Industry 4.0 concepts.

Keywords: Industry 4.0, processing of polymer materials, integrated information systems.

Przemysł 4.0
Cz. I. Wybrane aplikacje w przetwórstwie tworzyw polimerowych

Streszczenie: Przedstawiono przykłady zastosowań koncepcji Przemysł 4.0 w procesach produkcyjnych związanych z przetwórstwem tworzyw polimerowych. Implementacja struktury Przemysłu 4.0 ma na celu zwiększenie szybkości produkcji przy jednoczesnym zmniejszeniu liczby braków. Osiągnięcie takich rezultatów jest możliwe z wykorzystaniem zintegrowanych systemów informatycznych sprzężonych ze zautomatyzowanymi procesami produkcji i kontroli jakości. Na podstawie literatury i doświadczeń własnych stwierdzono, że przemysł przetwórczy wymaga stosowania tego typu zintegrowanych systemów w celu osiągnięcia dalszej poprawy konkurencyjności.

Słowa kluczowe: Przemysł 4.0, przetwarzanie materiałów polimerowych, zintegrowane systemy informacyjne.

The concept of Industry 4.0 at present is difficult to define precisely because the term was created in recent years and is interpreted in different ways in various sources, depending on the complexity of the structure. Generally it can be assumed that the term refers to computer-aided manufacturing systems integration based on complex data exchange algorithms combined into networks of varied structure. Some studies perceive Industry 4.0 as the next industrial revolution, yet in some cases this opinion seems disputable. Analysis of the concept in the context of industrial applications suggests that this is rather an extension of Product Lifecycle Management (PLM) system taking advantage of new information tools (Fig. 1). Operations of this type have been observed for at least a few years in such international corporations as Pratt & Whitney and GE, where data exchange in the manufacturing process generally takes place *via* integrated networks of computer systems based on CAD-I/CAx numerical data exchange standards. In Poland it is also possible to encounter Industry 4.0 type solutions implemented in manufacturing, particularly in automotive and related processing industries. As an example, SPLAST Company in its processes designed for manufacturing of products from polymer materials has implemented and is developing integrated systems based on structures of Industry 4.0. Owing to this approach to

[1)] Rzeszow University of Technology, Faculty of Chemistry, Department of Polymer Composites, Al. Powstańców Warszawy 6, 35-959 Rzeszów, Poland.
[2)] Rzeszow University of Technology, Faculty of Mechanical Engineering and Aeronautics, Al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland.
[3)] SPLAST Sp. z o.o., Lotników 13, 38-400 Krosno, Poland.
[4)] Rzeszow University of Technology, Faculty of Electrical and Computer Engineering, Al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland.
[5)] RDC Materials Sp. z o.o., Przemysłowa 69, 39-300 Mielec, Poland.
[*)] Author for correspondence; e-mail: molek@prz.edu.pl

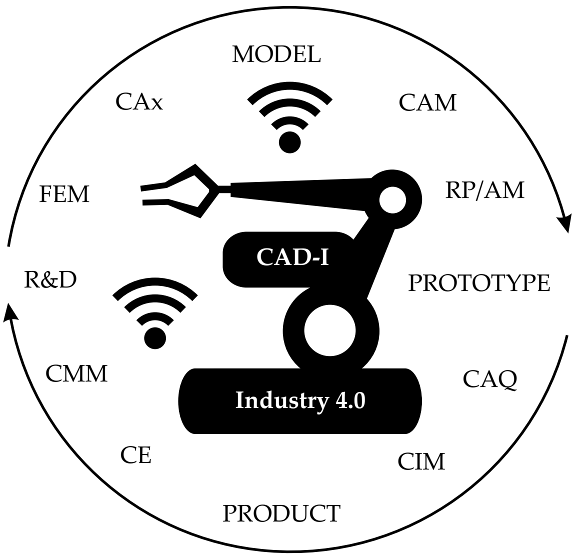

Fig. 1. Structure of Industry 4.0 as an extension of PLM system; CAD – Computer Aided Design, CAM – Computer Aided Manufacturing, CMM – Capability Maturity Model, CIM – Computer Integrated Manufacturing, CAQ – Computer Aided Quality Control, FEM – Finite Elements Method, AM – Additive Manufacturing, CE – Computer Engineering

the manufacturing process SPLAST Company was able to increase its effectiveness and simultaneously decrease the number of faulty products. R&D processes based on computer systems and on incremental models of rapid prototyping occupy an important place in the structure of Industry 4.0. Regarding this, SPLAST has its own R&D laboratory and cooperates with Rzeszow University of Technology in the area of simulations of polymer materials processing and rapid prototyping systems, as elements of Industry 4.0 structures. Another company involved in development of solutions designed for processing industry, SONDA SYS. isa – manufacturer of the first Polish industrial system for sintering of polymer powders (Selective Laser Sintering – SLS), as an Industry 4.0 ready equipment. Implementation of solutions for Industry 4.0 also requires specialists, therefore Rzeszow University of Technology conducts scientific research in this area and provides education to students particularly related to application of rapid prototyping methods, production management and engineering, as well as computerization of manufacturing processes.

INTEGRATION OF MANUFACTURING OPERATIONS IN POLYMER MATERIALS PROCESSING, BASED ON THE STRUCTURE OF INDUSTRY 4.0

Integration of design and prototyping processes

The schematic diagram (Fig. 1) shows that most elements characteristic for the structure of Industry 4.0 are present in PLM. The main task in the process of implementing Industry 4.0 concepts involves integration of various software and hardware related solutions to achieve multi-channel flow of data within temporal structures and in real time.

In view of the above, the main advantage of Industry 4.0 structure is its temporal multidimensionality whose integrative effect is decisive for accumulative decrease in duration of production [1–5]. This is particularly noticeable and important in mass production of components manufactured by means of injection molding. Elaboration of structures and processes integrated around product optimization can take place at the start, when 3D-CAD model is developed as CAD-I, *i.e.*, Computer Aided Design-Interfaces; this type of model may be described as 4D-CAD if the adopted procedure of making designs takes into account multidimensional structure, including the fourth dimension of time dedicated to further analyses in parallel time horizons. This will enable increased speed of virtual prototyping and physical prototyping based on the systems of Computer Aided Engineering (CAE) [6, 7], Finite Elements Method (FEM) and Additive Manufacturing (AM). Parallel organization at this stage also makes it possible to include the process of testing technological and functional prototypes generated by means of 3D printing. Testing of technological prototypes makes it possible to speed up preparation of the technological process for mass production. On the other hand testing of functional prototypes with properties similar to those in finished products enables rapid, nearly simultaneous refinement of the product at the prototype stage [8].

The schematic diagram in Fig. 2 presents in a simplified way the reduction of time needed for designing, producing and analysis of a product prototype. In reality reduction of time will depend on the complexity of the object. Notably, the gain will be greater in the case of more complex structures. It can be seen that a significant part of the process takes place in a numerical environment, therefore infrastructure related limitations (in

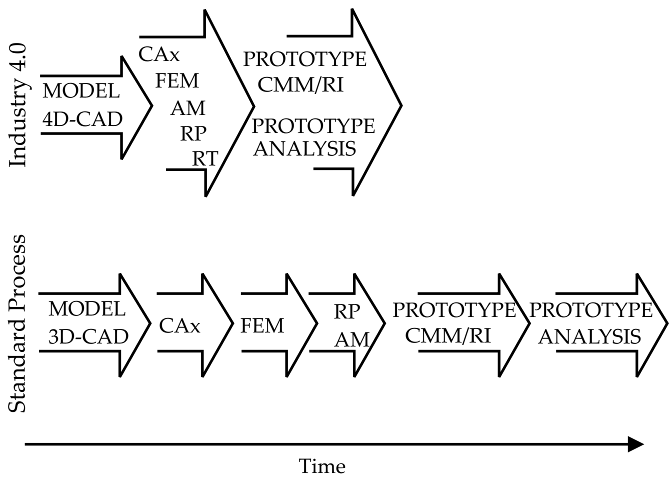

Fig. 2. Reduction of prototype production time in a standard process and an Industry 4.0 type process; RT – Rapid Tooling, RI – Rapid Inspection, RP – Rapid Prototyping

hardware and software) are not a key obstacle in speeding up the process. It is possible to use external subcontractors, linked with the relevant company *via* a network structure. The process of executing a 3D-CAD model generally remains unchanged in both cases [9–11]. Yet, here it is also possible to use procedures speeding up the modeling process, *i.e.*, the so-called program macros for defined product groups. Reduction of time results from a parallel approach to analysis based on Finite Elements Method and a parallel production of prototypes using 3D printers as well as prototype tools in the processes of Additive Manufacturing and Rapid Tooling (RT). It is possible to speed up geometric analysis of prototypes by applying Rapid Inspection (RI) processes based, *inter alia*, on 3D scanning. Integration of software and use of universal data exchange file formats enable implementation consistent with the structures of Industry 4.0 [11–16].

Integration of product manufacturing processes in an injection molding process

Mass production of goods from thermoplastic polymers with the use of injection molding is one of the manufacturing processes in which significant gains can be achieved if Industry 4.0 objectives are implemented. Notably, in this case the structure of Industry 4.0 is also an extension of the existing systems of production planning and quality monitoring based on computer aided solutions. At the first stage of production preparation, reduced duration of manufacturing is enabled by previously conducted design and simulation works, *e.g.*, resulting from the use of injection molds with conformal channels (Fig. 3).

Importantly, during the entire process it is necessary to examine properties of input materials and parameters of the injection process, to inspect molded pieces as well as, *e.g.*, imprints on the pieces. Monitoring operations with feedback should be carried out in real time, in a continuous mode. As a result it is possible to minimize waste by using continuous recycling. Owing to this, once a defective product is identified, it is forwarded directly to the mill from which it is sent back as input material to be re-injected. Consequently there is no need for storing and then milling the defective products, and for drying the regranulate [17].

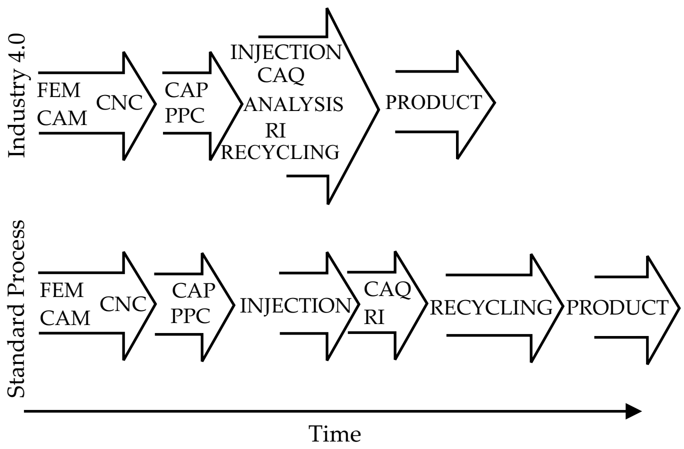

Fig. 3. Reduction of product production time in a standard process and an Industry 4.0 type process; CNC – Computerized Numerical Control, CAP – Computer Aided Planning, PPC – Product Planning and Control

COMPUTERIZED PROCESS INTEGRATION

Integration of manufacturing processes [18–20] across the borders of specific production plants has become a reality, consequently it is necessary to design and develop schemes enabling cooperation between different economic entities, to be facilitated not only by interconnected computer networks but also by integrated technology and manufacturing systems. Solutions of this type should make it possible to collect data from machines used in the process of prototyping and manufacturing and then enable their analysis, *e.g.*, by an expert system. Such operations may help to streamline the processes of prototyping and manufacturing and may promote the use of evolutionary methods of control, correction and data specification taking advantage of mechanisms based on feedback loop.

In order to introduce such solutions it is necessary to take into account the following issues:

– Synchronization of works.

It is necessary to develop a methodology for managing a distributed prototyping process. For practical reasons, the process should be centralized. Obviously the process may be coordinated and controlled by technicians. Yet, this significantly reduces flexibility of resources management and makes it difficult to introduce a methodology of round-the-clock prototype engineering, such as follow-the-sun (FTS) and role-based access control (RBAC) [3, 4]. In this case it may be highly advantageous to implement a central automated mechanism driving the prototyping process based on a programmable arbiter. Obviously the functioning of the system will be based on incomplete information, and due to this support from technical personnel will be necessary, yet it will not be required on a continuous basis.

– Communication environment.

Environment used for communication in a distributed prototyping environment is of heterogeneous nature, therefore it poses serious difficulties in administration and in creating communication clusters. In order to comply with rapid prototyping (RP) requirements it must enable rapid reconfiguration, as well as setting up of encoded and safe communication for the work groups; it must facilitate control of access to the machines, ensure specified transmission parameters, and comprise a consistent, uniform system of network management.

– Control at the stage of a physical object production.

Remote manufacturing is linked with a necessity to develop methods and tools enabling verification of quality parameters in the final object, both at the stage of production and at the very end of the process. Given the diversity of methods and technologies applied in manufacturing of such objects, it is necessary to define adequate solutions suitable for a given situation. One of the universal tools which can be used for this purpose is analysis of high resolution images; based on these it is possible to perform remote comparison of the manufactured object and the digital model. However, given the nature and scope of the related works, this issue is not covered by this article.

– Safety and confidentiality.

Given the fact that in many cases rapid prototyping processes involve the use of novel solutions and innovations, it is necessary to develop policies, methods and measures to ensure safe flow of information between the distributed components of the prototyping process. Yet, the authors did not discuss the related issues in this paper.

System structures

Each stage of a rapid prototyping and manufacturing process plays an important part in the system. Yet, in this study we will focus on information exchange between the specific components constituting the entire manufacturing process. Up until now the process very often takes place in a single production plant and all the elements of a workstation, *e.g.*, dedicated to rapid prototyping are located relatively close to one another. In such a situation data exchange does not pose great challenge. However, the problem takes on a new meaning, in view of the fact that it is necessary to develop novel solutions promoting development of Industry 4.0 and to design technologies facilitating cooperation between distributed economic entities. It seems advanced computer networks should naturally be used for this purpose. This way it will be possible to ensure rapid and reliable exchange of information (data) between the specific distributed components of the rapid prototyping process.

A schematic drawing of a typical network infrastructure enabling integration of distributed elements taking part in a rapid prototyping process is shown in Fig. 4. The use of broadband computer networks makes it possible to place the specific components in locations situated at a distance from one another, and as the same time to retain adequate transmission quality parameters.

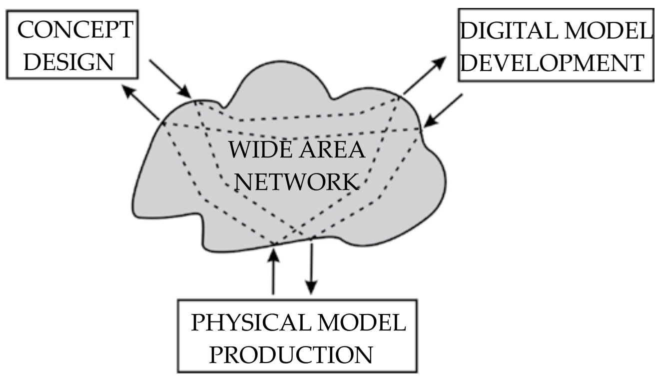

Fig. 4. System structures

Data management and security

The above approach also presents certain drawbacks and limitations:

– Static configuration of network parameters.

To ensure adequate quality of service parameters for data transmission in a rapid prototyping process, it is necessary to implement adequate policies for management of transmission parameters, such as: capacity, priorities, queuing mechanisms at intermediate nodes, *etc*. However, since manufacturing processes are independent from computer network processes, typical computer networks lack mechanisms adjusting values of these parameters to dynamic changes in flows accompanying the processes of prototyping.

– Lack of support for dynamic relocation of resources.

In contemporary industrial environment new resources may appear constantly to support rapid prototyping process, existing resources may be relocated, and outdated resources may in liquidated. Consequently, advanced communication infrastructures should ensure tools enabling rapid reconfiguration of the network environment to ensure continuity of the manufacturing processes. Unfortunately, a conventional wide area network does not have such functionality.

– Heterogeneity of technical solutions.

Various operators frequently functioning in a distributed networking environment use different hardware platforms and protocols designed for monitoring and control of their own infrastructures.

The above limitations pose a serious hindrance, and at times make it impossible to develop an effective and reliable system for distributed communication to support rapid prototyping processes. The problem may be solved by applying Software-Defined Networking within a computing environment.

CONCLUSIONS

In view of market globalization, large competition and noticeable shortage of qualified technicians and engineers, manufacturers are forced to quickly develop innovative solutions based on multifaceted controlled automatic systems using network computing structures.

Observations related to processes occurring in the contemporary market of manufacturers show that today the entire design and prototyping process is less and less likely to be completed within one company or a single department operating in a given consortium. Entities taking part in design development, prototyping and structural analysis are very often geographically scattered, therefore it is necessary to employ advanced communications technologies to ensure fast and reliable data exchange between them. Manufacturing clusters, special economic zones, *etc.* are an excellent example of relationships of this type. Therefore, a perfect solution enabling integration of distributed resources is provided by advanced computer networks. In view of the above, implementation of Industry 4.0 concepts is a necessity for those wishing to survive in the market of mass production. This is also applicable to polymer materials processing sector. More and more products are manufactured from polymer materials with the use of injection molding technique. These include complex automotive components. In such a case the structure of Industry 4.0 comprises practically all subcontractors contributing to the final product. In view of the above, structures of this type must be implemented as soon as possible by enterprises which want to achieve competitive advantage in the market of polymer materials processing.

REFERENCES

[1] Lasi H., Fettke P., Kemper H.-G. *et al*.: *Business & Information Systems Engineering* **2014**, *6*, 239. http://dx.doi.org/10.1007/s12599-014-0334-4

[2] Strange R., Zucchella A.: *Multinational Business Review* **2017**, *25*, 174. http://dx.doi.org/10.1108/MBR-05-2017-0028

[3] Kroll J., da Silva Estácio B.J., Audy J.L.N., Prikladnicki R.: "An Initial Framework for Researching Follow-the-Sun Software Development", Global Software Engineering (ICGSE), IEEE 9th International Conference on, Shanghai, China 2014, pp. 116–124. http://dx.doi.org/10.1109/ICGSE.2014.21

[4] Fu Y., Liu Y., Liu D. *et al*.: "An environment based RBAC model for internal network", Computer Communication and the Internet (ICCCI), IEEE International Conference on, Wuhan, China 2016, pp. 91–94. http://dx.doi.org/10.1109/CCI.2016.7778884

[5] Choi H., Samavedam S.: *Computers in Industry* **2002**, *47*, 39. http://dx.doi.org/10.1016/S0166-3615(01)00140-3

[6] Ladyman J., Lambert J., Wiesner K.: *European Journal for Philosophy of Science* **2013**, *3*, 33. http://dx.doi.org/10.1007/s13194-012-0056-8

[7] Grabowski F.: *Complexity* **2013**, *18*, 28. http://dx.doi.org/10.1002/cplx.21438

[8] Grabowski F., Paszkiewicz A., Bolanowski M.: *Journal of Applied Computer Science* **2013**, *31*, 29.

[9] Bolanowski M., Paszkiewicz A.: "Methods and Means of Creation Application to Control a Complex Network Environment", Software Engineering Research for the Practice, Polish Information Processing Society 2017, p. 151.

[10] Paszkiewicz A., Bolanowski M.: "Towards a Synergistic Combination of Research and Practice in Software Engineering" (Eds. Kosiuczenko P., Madeyski L.), Springer International Publishing 2017, p. 193.

[11] Brettel M., Friederichsen N., Keller M., Rosenberg M.: *International Scholarly and Scientific Research & Innovation* **2014**, *8*, 37. scholar.waset.org/1307-6892/9997144

[12] Linkov A.M., Rybarska-Rusinek L.: *International Journal of Solids and Structures* **2010**, *47*, 3297. http://dx.doi.org/10.1016/j.ijsolstr.2010.08.004

[13] Linkov A.M., Rybarska-Rusinek L.: *International Journal of Engineering Science* **2012**, *61*, 87. http://dx.doi.org/10.1016/j.ijengsci.2012.06.012

[14] Rejwer E., Rybarska-Rusinek L., Linkov A.M.: *Engineering Analysis with Boundary Elements* **2014**, *43*, 105. http://dx.doi.org/10.1016/j.enganabound.2014.04.001

[15] Jaworski D., Linkov A.M., Rybarska-Rusinek L.: *Computers and Geotechnics* **2016**, *71*, 295. http://dx.doi.org/10.1016/j.compgeo.2015.04.017

[16] Stock T., Seliger G.: *Procedia CIRP* **2016**, *40*, 536. http://dx.doi.org/10.1016/j.procir.2016.01.129

[17] Aboulkhair N.T., Everitt N.M., Ashcroft I., Tuck C.: *Additive Manufacturing* **2014**, *1–4*, 77. http://dx.doi.org/10.1016/j.addma.2014.08.001

[18] Weyer S., Schmitt M., Ohmer M., Gorecky D.: *IFAC-PapersOnLine* **2015**, *48*, 579. http://dx.doi.org/10.1016/j.ifacol.2015.06.143

[19] Kolberg D., Zuhlke D.: *IFAC-PapersOnLine* **2015**, *48*, 1870. http://dx.doi.org/10.1016/j.ifacol.2015.06.359

[20] Dziubek T.: *Polimery* **2018**, *63*, 49. http://dx.doi.org/10.14314/polimery.2018.1.8

Received 22 I 2018.