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INFORMATION AND DECISION SYSTEM SUPPORTING THE PRODUCTION OF ADI CAST IRON PRODUCTS

The presented article concerns the issue of supporting the ADI cast iron product manufacturing process and presents an IT system dedicated mainly to designers and technologists. Designers can be supported at the stage of selecting types of materials and technologies (including ADI cast iron) to produce products with required properties. Technologists can obtain support in determining the parameters (temperature and chemical) of the ADI cast iron manufacturing process in order to obtain products with specific properties. The system also contains an information resources (standards, documentation, examples) concerning ADI cast iron and products made of it. Examples of use by individual system users are presented as a case study.

Keywords: Decision support, Information system, ADI casting, austempered ductile cast iron, ADI

1. Introduction and related works

The ADI (Austempered Ductile Iron) cast iron is made by heat treatment of ductile iron. The austenitizing and isothermal hardening process has a positive effect on the elongation and tensile strength of ductile iron, making it comparable to some types of cast steel or wrought steel. ADI cast iron has an ausferritic matrix which enables good resistance to cracking and abrasive wear [1,2]. There are many varieties of ADI cast iron differing in the form of graphite, matrix or the method of obtaining an ausferritic structure, thanks to which we can obtain various mechanical and functional properties. ADI cast iron is used for transmission components, vehicle body parts, agricultural machinery components and many other machine and device components where material conversion is profitable depending on the size of the batch or the final parameters of the product [3,4].

Industry 4.0 Concept puts great emphasis on flexibility in the production process resulting in new challenges especially small and medium-sized foundries [5]. Achieving high flexibility while maintaining high productivity requires the application of IT systems at different levels of the organization and the production process. These can be production [6], energy or manufacturing process [7] management systems. The flexibility of production may also affect the production process, making it even more complex [8,9]. A separate group of such systems in the metal casting industry are decision support systems, which are becoming increasingly popular [10]. With many manufacturing methods, it is possible to accurately track each production step. This enables the development of a system supporting the production process not only integrated with each of the machines involved in the process, but with unambiguous identification of the product at each production stage. Such a system should be supplied with data of high reliability [11]. For tracking and data collection in foundries, the situation can be much more difficult. This applies in particular to the traceability of individual castings, the chemical composition of the metal from which they were cast and the processes related to the processing of this metal. In many cases, it is necessary to use separate IT tools enabling the identification of the casting and related processes [12]. The recorded data coming from the manufacturing process of castings may show large spreads and come from various sources. However, there are mathematical and numerical methods that can work under these conditions [13]. There are also many various IT solutions used in foundries, positively influencing the performance of new products and process flexibility. These include programs such as CAM, CAD, CAE, liquid metal control systems [14] or metal solidification curves analysis systems [15]. Some of them are based on the analysis of microscopic images [16]. There are also systems supporting the product manufacturing process by developing tools supporting the quality control process [17]. Some of them provide support at the stage of determining process parameters to obtain products with specific parameters [7].

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Analyzing the dynamic development of decision-making systems and the dissemination of their use in supporting process of production in accordance with the Industry 4.0 concept, in combination with the situation in which ADI cast iron still seems to be an underestimated material despite its specific properties and advantages, we decided to develop a system to support the process of manufacturing products from this material. The main goal was to create an IT system that would enable the storage and use of expert knowledge regarding the selection of materials and technologies for the production of products with specific properties (not only from ADI cast iron) and support for technologists in determining the parameters of the manufacturing process of products that can be made of ADI cast iron. An additional element of the developed system is a catalog of materials and technologies with their properties, enabling the search and comparing individual materials and technologies in terms of their properties and applicability.

2. The system architecture

As part of the developed solution, an IT system was created to support the process of manufacturing ADI cast iron products, which additionally has information useful for manufacturing products from other materials and technologies. The most important modules of this system are shown in Fig. 1.

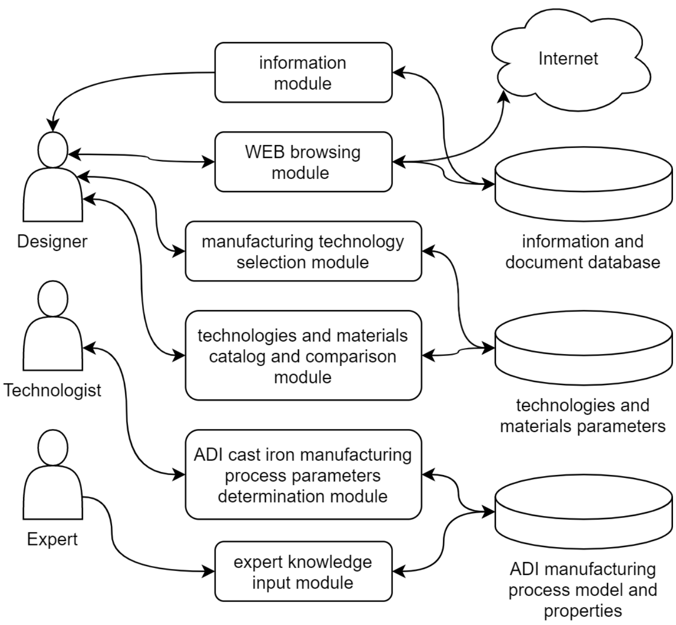


Fig. 1. The Main modules and components of the system

The users of this system can be divided into 3 types. The first group are Designers and Constructors, marked in Figure 1 as the "Designer" user, who during their work are faced with the task of choosing the technology and material from which a given product should be manufactured, depending on its target parameters (durability, size, functional characteristics, etc.). Such users will mainly use the "Manufacturing technology selection module", which will enable them to match the technology and material of manufacture to a product with specific parameters. Other components that can be used by users from this group are the "information module", which contains detailed information on ADI cast iron, and the "WEB browsing module", allowing for automatic acquisition of new data from publicly available Internet resources, which are described later in this chapter. The second group of users are technologists who control the product manufacturing process in the foundry hall. They can use a dedicated component that allows the determination of detailed parameters of the manufacturing process of a specific grade of ADI cast iron, to obtain products with specific mechanical or quality parameters. The third group of users are experts, who provide domain knowledge enabling the system to implement its main functionalities. They are not the direct beneficiaries of the system and are more of a source of data and information on the basis of which the system supports designers and technologists.

Manufacturing technology and material selection module

The main functionality of this component is the implementation of conclusions based on the expert knowledge on the selection of material and manufacturing technology for specific parameters of the final product. The module is intended mainly for constructors or designers who specify desired properties of the final product, and the system provides them with a list of materials and technologies that enable the production of products with specific properties. The operation scheme of this module from the end user perspective is shown in Fig. 2.

The steps of the system operation and cooperation with the user are:

I. The user selects the required parameters of the final product from the following categories (the user interface is presented in Fig. 3) :
   A. Mechanical properties (Rm, A, Re, K, HB),
   B. Performance properties (elevated temperatures, lowered temperatures, corrosion resistance, erosion resistance, vibration damping, property anisotropy),
   C. Application examples (rakes, gears, rocker arms, cylinders, crankshafts, parts working in the ground),
   D. Dimensions (product weight, series size, wall thickness (range), dimensioning accuracy, necessity to use cores).

II. The system matches the material and manufacturing technology for these criteria.

III. If at least one of the materials meeting the selected criteria is one of the ADI cast iron grades, the system determines the heat treatment parameters and the chemical composition of the base cast iron for the ADI cast iron manufacturing process (described in detail later in the paper as the functionality of the next module).

IV. The system allows you to view detailed properties of materials that meet the selected criteria and to launch a comparison engine based on the returned results.

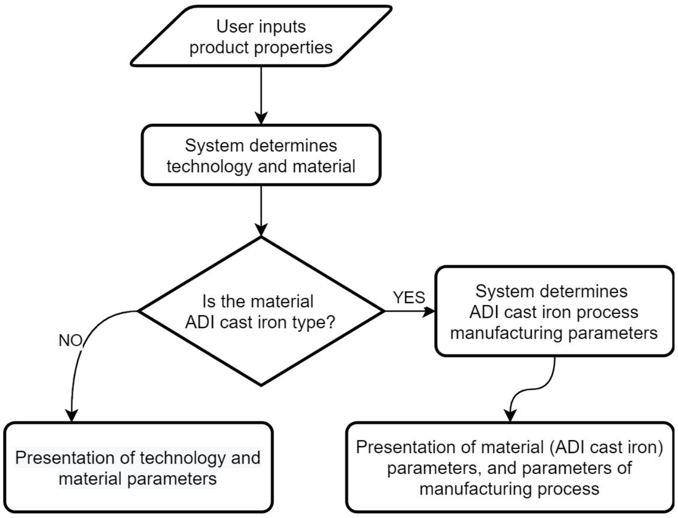


Fig. 2. The algorithm for determining the technology and material of the product with specific properties

Module for determining the parameters of the ADI cast iron manufacturing process for specific parameters of the final product

Additional information required to determine the detailed parameters of the ADI cast iron manufacturing process by the system is providing by the user (technologist) the approximate value of the wall thickness of the final product. The production process parameters calculated with this component are the chemical composition of the base cast iron and the temperature treatment parameters in the ADI cast iron production process. An example of using this component is presented in chapter 3.

To implement this functionality, it was necessary to develop a solver – an algorithm that calculates the parameters of the chemical composition (C, Si, Mn, Ni, Mo, Cu) of the base cast iron and thermal treatment parameters (temperature of austenitization and hardening) for the ADI cast iron manufacturing process depending on provided wall thickness of the manufactured product, and taking into account the parameters of the output product previously specified by the user in the system interface (mechanical and performance properties, dimensions, application). The experimental data on the process parameters and the formulae on the basis of which the algorithm was developed were provided by technological experts of the Foundry Research Institute in Krakow. The formula defining the equation for the wall thickness of the product (G_s) on which the solver model is based is given by Eq. (1).

$$\begin{aligned} G_s = {} & (124{*}C_x) + (27{*}Si) + (22{*}Mn) + \\ & + (16{*}Ni) - (25{*}Mo) - (1{,}68{*}10^{-4}{*}T_h^{\,2}) + (12{*}Cu{*}Ni) + \\ & + (62{*}Cu{*}Mo) + (88{*}Ni{*}Mo) + (11{*}Mn{*}Cu) + \\ & + (127{*}Mn{*}Mo) - (20{*}Mn{*}Ni) - 137 \end{aligned} \tag{1}$$

where:

$C_x = (C_{x1} + C_{x2})/2$ – estimated content of carbon in austenite,

$C_{x1} = T_a/420 - (0{,}17{*}Si) - 0{,}95$

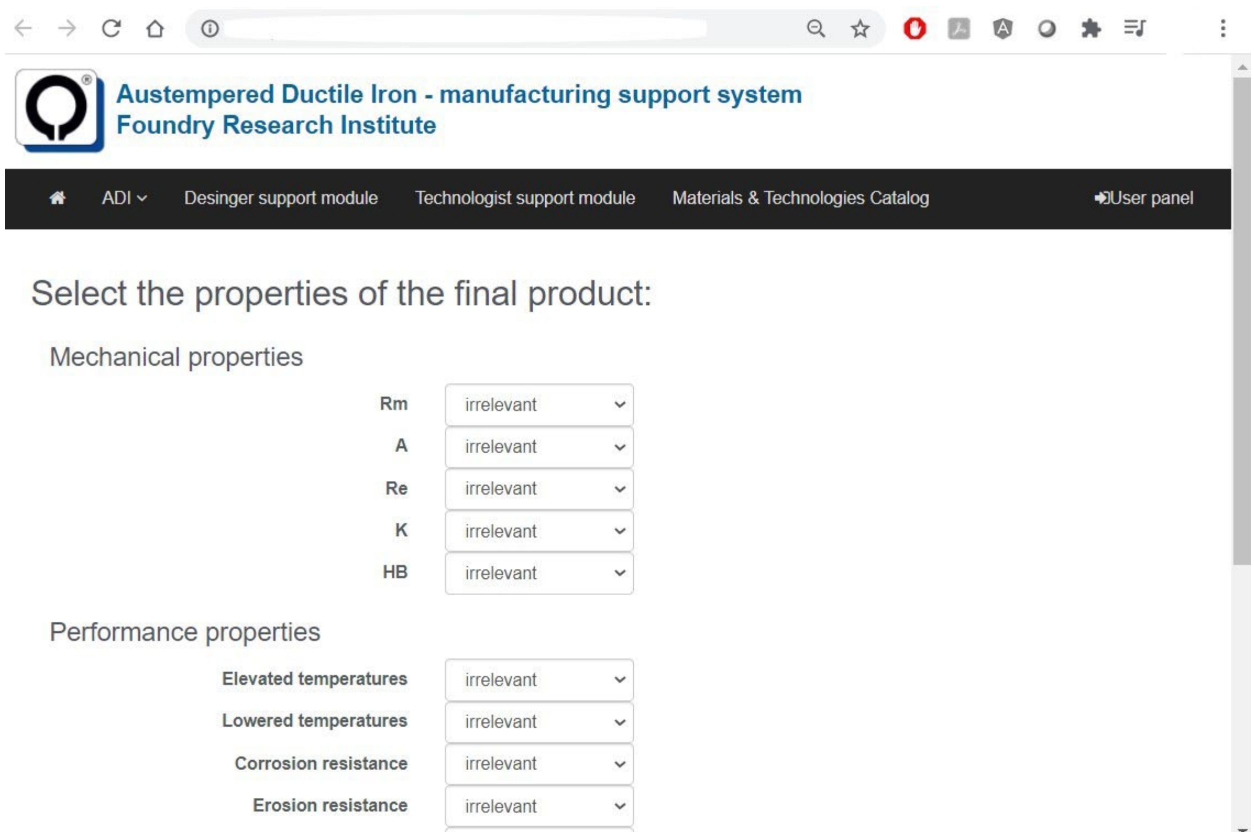


Fig. 3. User interface for selecting the parameters of the final product

$C_{x2} = -0{,}435 + ((0{,}335*10^{-3})*T_a) + ((1{,}61*10^{-6})*T_a^2) + (0{,}006*Mn) - (0{,}11*Si) - (0{,}07*Ni) + (0{,}014*Cu) - (0{,}3*Mo)$

T_h – hardening temperature

T_a – austenitizing temperature.

Based on the Eq. (1), as well as the Max and Min ranges for the elements C, Si, Mn, Ni, Mo, Cu and the T_h and T_a temperatures (presented in Table 1), the parameters of Eq. (1) (percentage composition of elements and temperature) are calculated using method PSO (particle swarm optimization) to get the result (wall thickness) given as an input parameter. It should be noted that the Eq. (1) is not a unimodal function, i.e. the desired wall thickness can be obtained for various sets of parameters for strictly defined ranges of elements and temperatures.

TABLE 1

The default ranges of values for calculation

	C	Si	Mn	Ni	Mo	Cu	Th	Ta
Min	3,4	2,5	0,2	0	0	0	300	830
Max	3,8	2,8	0,35	2	0,2	0,8	390	900

The solver allows to change the parameter ranges that affect the calculation of the target values. Boundary parameters can be changed in the previous steps of system operation (depending on the designated ADI grade of iron and any wall thickness given as a range) and are passed to the solver as an input parameter along with the exact wall thickness of the product specified by the user (as presented in Fig. 4). The method used to implement the solver is the PSO method based on the observation of nature, described in detail in the literature [18]. The key element of this algorithm is the objective function, which was defined by Eq. (2).

$$F(i) = abs(C_{wt}(i) - S_{wt}) \quad (2)$$

where:

$C_{wt}(i)$ – the calculated wall thickness for a given i'th particle,

S_{wt} – expected wall thickness.

Technologies and materials catalog and comparison module

The main functionality of the material catalog module is collecting all data stored in the system and presenting them in a transparent form for the system user. Additional functionalities of this module are a material search engine and a comparison engine based on detailed properties of materials and technologies. Examples of the use case of this module are presented in chapter 3.

WEB browsing module

Another component available as part of the system is the pattern search module within the public, open resources of the Internet, which is dedicated to designers, constructors and system administrators, in order to search potentially valuable domains, that may contain information that may be used to extend the resources of the system . It uses advanced IT solutions based on crawling and scraping methods [19], which are not crucial in the aspect considered in this article.

Information module

This module provides information on the ADI cast iron material, its production technology, properties and applications of products made of this material. The system stores standards for various ADI cast iron grades, detailed physicochemical characteristics of the products as well as articles and documents related to this area. This entire section is a mini-portal that can be browsed in a way similar to Wikipedia.

Expert knowledge input module

The expert knowledge input module enables providing data into the system by domain experts. Using this module, they can add information both about materials and manufacturing technologies as well as detailed parameters for the production of ADI cast iron products, based on which the previously described modules operate.

3. Case Study

As part of the Case Study presentation, documenting the usefulness of the presented system, the use of its three key components was presented:

- Manufacturing technology and material selection module,
- Module for determining the parameters of the ADI cast iron manufacturing process for specific parameters of the final product,
- Technologies and materials catalog and comparison module.

In order to determine the materials and technologies to manufacture a product with specific parameters, user should define them in the user interface presented in the previous chapter in Fig. 3. In the described case, the following mechanical properties were selected: Rm in the range 650-900 and elongation A5 in the range of 8-14%. The results of the system operation are presented in Figure 4.

The system returned to the user a list of materials that can be used for the manufacturing of products with parameters selected by the user. At the end of this stage, the user has the options to:

- Preview of detailed material properties after clicking on the material name,
- Compare individual materials and technologies from the list of results,
- Determine the detailed parameters of the ADI cast iron manufacturing process (if ADI cast iron is one of the available materials).

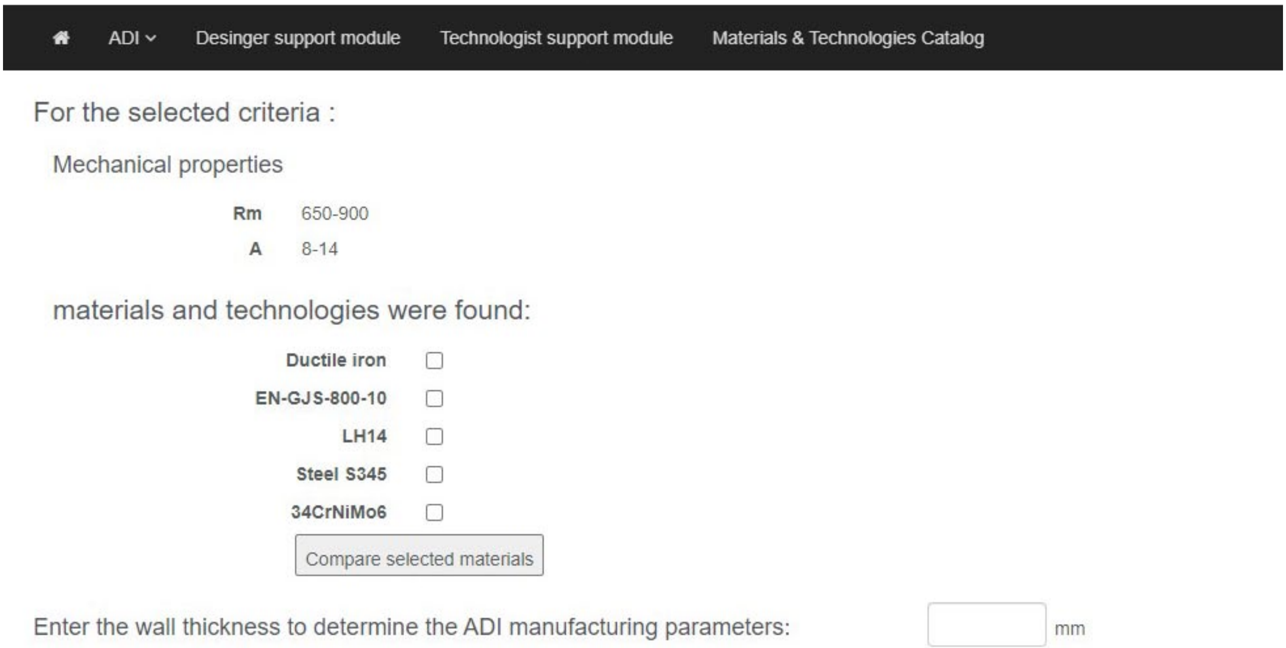


Fig. 4. Designation of materials that meet the criteria for the final product

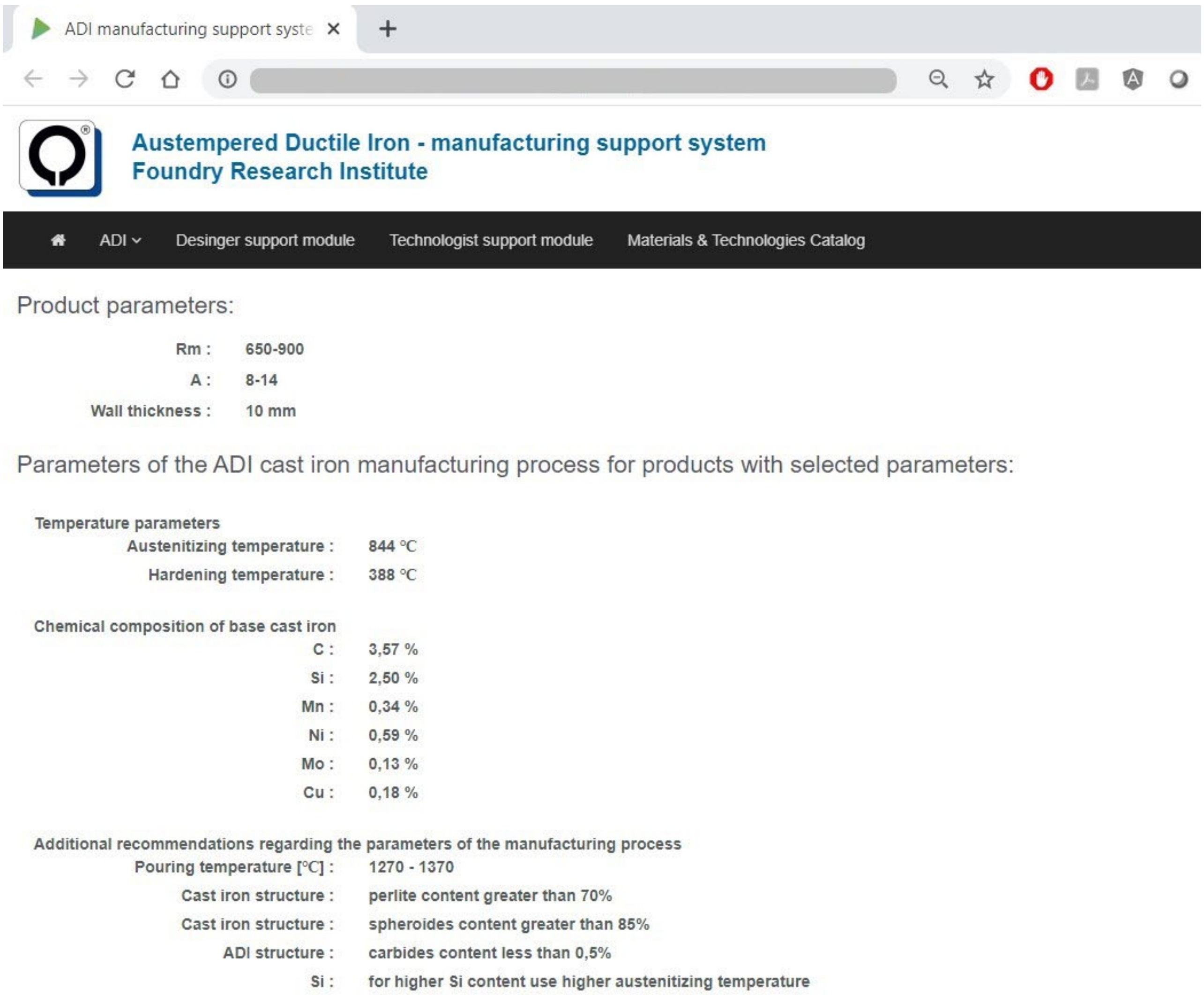


Fig. 5. Determining the parameters of the ADI cast iron manufacturing process for a product with a specific product wall thickness and mechanical properties

To perform the third option, it is necessary to determine the wall thickness of the target product. In the presented example, the user selects the value of 10 mm and the results of determining the detailed parameters of the ADI cast iron manufacturing process are shown in Fig. 5. Part of them are calculated by the solver algorithm described in previous chapter and the rest come from the knowledge database of the expert system that is part of the system.

The particular parameters of the ADI cast iron manufacturing process presented in Fig.5 concern:

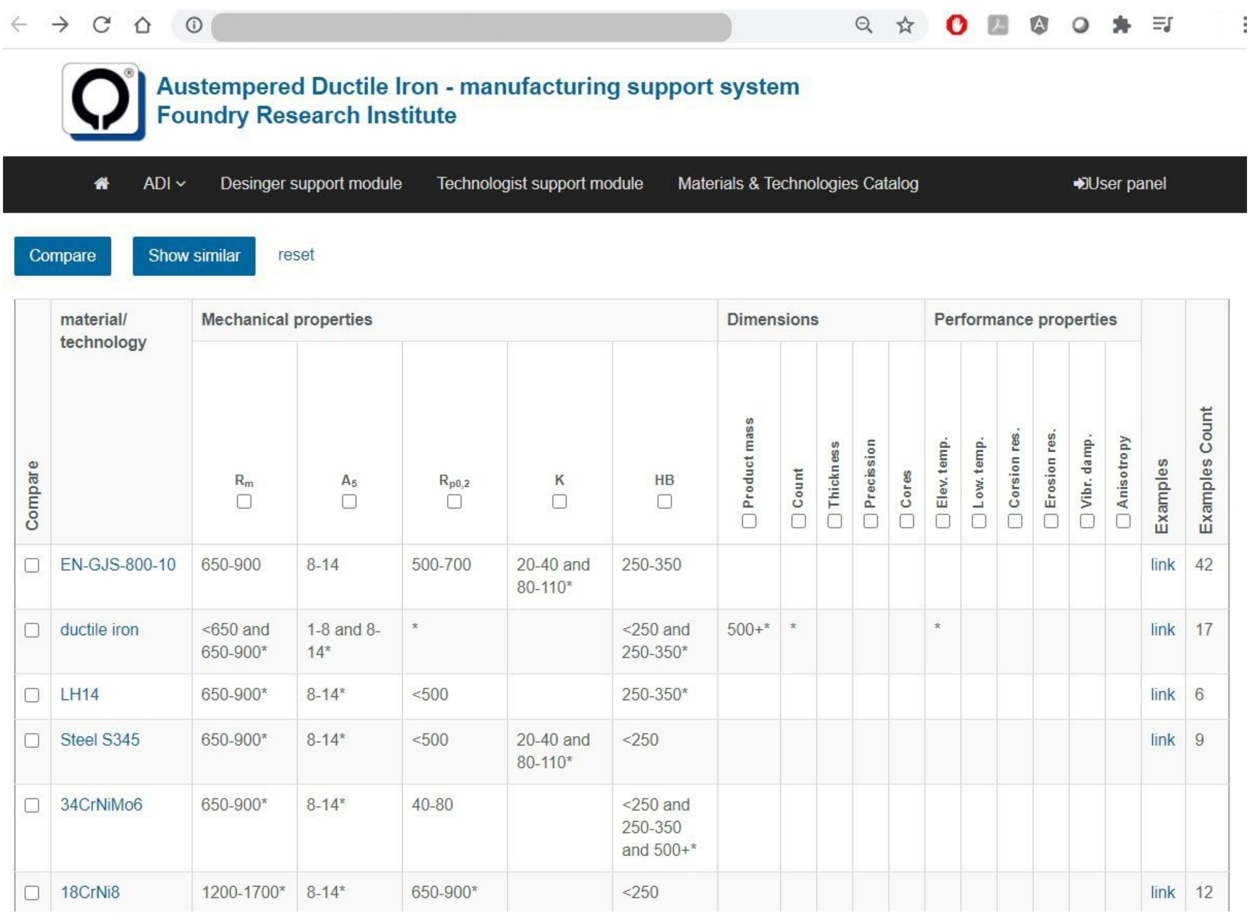
a) Temperature parameters of the manufacturing process,
b) Chemical composition of base cast iron,
c) General guidance on values recommended for the manufacturing process (independent of the criteria given by the user, specific to a given grade of ADI ductile iron).

The third main functionality of the presented system is the catalog module, material search and comparison engine, an example of which is shown in Figure 6. The system database stores the characteristics of 52 materials and manufacturing technologies, the total number of sample products exceeds 300. Using the graphical user interface presented in Figure 6, the system user can search for materials with properties similar to the material selected by the user ("base material"). To perform such a search, the user first selects the base material (by selecting it in the „Compare" column) and then select the properties that should be taken into account when determining the similarity (checking the checkboxes in the "Compare" row). After clicking the „Show similar" button, the system will return materials with similar properties (within the same ranges) as the base material.

An asterisk next to the value of a given parameter means that there are some remarks stored in the system for a given value, available to the user after hovering over a specific cell in the table. As a part of functionalities of this component, user can also compare and view the properties of individual materials and technologies. Details of the properties of specific materials and technologies are available after clicking on a specific element from the list.

4. Conclusions

The presented paper presents the IT support system focused on the production of ADI cast iron products. The paper describes the main components of the system, including the details of the solver used to determine the chemical parameters of the base cast iron and the temperature parameters of the ADI cast iron manufacturing process. As a case study, examples of the use of the system by a designer and technologist in order to determine the materials and technology of manufacturing a product with specific mechanical properties and to support the ADI cast iron manufacturing process itself by suggesting its process parameters were presented.


Austempered Ductile Iron - manufacturing support system
Foundry Research Institute

ADI | Desinger support module | Technologist support module | Materials & Technologies Catalog | User panel

Compare | Show similar | reset

Compare	material/ technology	Mechanical properties: R_m	A_5	$R_{p0,2}$	K	HB	Dimensions: Product mass	Count	Thickness	Precission	Cores	Performance properties: Elev. temp.	Low. temp.	Corsion res.	Erosion res.	Vibr. damp.	Anisotropy	Examples	Examples Count
☐	EN-GJS-800-10	650-900	8-14	500-700	20-40 and 80-110*	250-350												link	42
☐	ductile iron	<650 and 650-900*	1-8 and 8-14*	*		<250 and 250-350*	500+*	*				*						link	17
☐	LH14	650-900*	8-14*	<500		250-350*												link	6
☐	Steel S345	650-900*	8-14*	<500	20-40 and 80-110*	<250												link	9
☐	34CrNiMo6	650-900*	8-14*	40-80		<250 and 250-350 and 500+*													
☐	18CrNi8	1200-1700*	8-14*	650-900*		<250												link	12

Fig. 6. Catalog, search and comparison engine of materials and technologies

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