Considerations Regarding the Recalibration of the Manufacture of Castings from the Perspective of the Development of the Circular Economy

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Abstract. The paper presents the issue of recalibration of cast parts from the perspective of the circular economy, by presenting the specific issue, by setting the main objective of the study, that of identifying areas that require interventions in the technological process and ensuring socio-economic functionality. The analysis, in general, includes the presentation of the specifics of the analyzed process, the construction of assessment indicators of the circular economy and the quantification and hierarchy of the influencing factors. Particular attention is paid to the quantitative indicators and value appreciation of the manufacture of castings to the rigors of the circular economy. At the level of interpretive analysis, are presented the critical areas that require a multidisciplinary intervention to ensure the specific conditionalities of the circular economy.

1. Considerations for addressing the issue of the circular economy in the manufacture of castings

In tackling the proposed theme, the following considerations were taken into account: the importance of the circular economy in the context of current economic and social developments, the influence that materials engineering has on the specific developments of circularity, the interest of Romanian specialists, both theoretical and practical, including among these the achievements of the authors of this paper as well.

For the first consideration, one where engineering must play a key role, are taken into account, by proper management of the manufacturing processes of products and services, in order to achieve the proposed functionalities, energy and material consumption in a circuit that considers their entire life cycle.

In this process, materials engineering has a special influence, a topic which includes the issue of elaboration, processing into utility products for various industries, shaping by various processes in functional geometric structures suitable for various components of machines and equipment, tracking operational safety and recovery, at the end of the life cycle, in order to reintroduce in the different manufacturing processes the materials included in the various functional structures.

By defining “materials engineering” in this way, we consider that “castings manufacturing” also falls into this category, with the specification that it is one of the best technological examples with...
adaptability to the circular economy, which is why we conducted a study on recalibration of the castings industry to the new requirements of the circular economy.

The third consideration is related to the fact that among Romanian specialists there were significant concerns regarding the promotion of the circular economy, both theoretically and practically. At a theoretical level, the work “La croissance: Entropie – Ecologie – Economie” [1] by Nicholas Georgescu-Roegen stands out, in which an extension of the entropy law to economic problems is made, the theoretical bases of the circular economy in which we have to deal with a decrease in terms of the potential of resources needed in the conduct of various technological processes.

At a pragmatic level, the “first metallurgy magazine” in Romania stands out, published in 1938, which justifies, on the principles of the circular economy, the construction of a steelworks in a company specialized in plastic deformation (lamination, wire-drawing, obtaining nails and other metallurgical products). Some of the measures taken for the rational use of metallic materials, revolutionary at the level of the interwar period, are present in the mentioned paper, among which we mention the following: “reuse of scrap metal; methods suitable for the execution of a thing with a minimum of material cost; constructive forms adapted to the demands and qualities of the materials; ennobling steel by adding other materials to increase its strength; protection against acid and moisture attack.” [2] At the same time, the presence at the “Dusseldorf Exhibition of 1938” [2] highlights the concerns in the 1930s regarding the rational use of resources, giving examples of the production of synthetic petrol from coal or in obtaining synthetic rubber from coal and lime. In the same context, it is emphasized the existence of a stand for “used materials”, which aims “to draw everyone’s attention to all those materials, which, not being immediately useful, are discarded. The exhibition aims to show that old things have an appreciable economic value, they can be used to manufacture new objects, thus having the character of raw material. And, in order for the visitor to keep in mind the importance of used raw materials, it is shown in detail how they are sorted, what operations are then subjected to, with which machines are processed and what manufactured products they can give rise to.” [2].

Regarding the concerns of the authors of this paper, they have developed numerous studies on the application of the circular economy in the manufacture of castings, including: “Rudology of the manufacture of castings”, "Methodology for assessing the manufacture of castings from the perspective of the circular economy” [3], “Engineering of the institutionalization of the circular economy in the manufacture of castings” [4] or “Engineering of the circular economy and good management of material resources” [5].

In structuring the analysis, two fundamental works were used, one related to “Circular economy. Economic systems and resource limitation” [6] and the other related to specifying the relations between “engineering and the environment in the castings industry” [7].

2. The objective of the study and the way of performing the analysis

The proposed study on recalibration of castings manufacturing, as a component of wrought materials engineering, aims to identify areas that require interventions in technological processes and socio-economic operations from the perspective of institutional development of the circular economy.

The analysis is performed by taking into account the following constituent elements: the specifics of the technological process; use and adaptation of assessment indicators; quantification and ranking of influencing factors.

The first element, that of the specificity of the cast products industry from the perspective of the circular economy, aims at an evaluation of the technological process, the evaluation of the materials entered in the technological process, the evaluation of the environmental impact and the evaluation of the circularities that are ensured.

The second element, that of loading with institutional value the indicators adapted and used in the quantitative and value assessment of the manufacture of castings to the rigors of the circular economy, considers the proposal of the following evaluation structure:
3. Materialization of the procedure for substantiating the study

The materialization of the substantiation procedure of the study was achieved by quantifying the production in a cast iron foundry over a period of seven years and reporting it to the level of environmental costs and investments made in that period, identifying areas of intervention to ensure economic development in the calibration process.

In order to have a basis on the total account of the materials entered in the technological process, the scheme from Figure 1 is used, which shows the inputs of the materials in the technological process and the output of the delivered cast parts and the useless part generated in the technological process, and in Table 1 their quantitative values are shown, as an average of the 7-year analysis performed.

The values identified on environmental expenditures and environmental investments for the same period are presented in Table 2.

For the situation taken into account in the analysis, Table 3 presents the calculated values of the reporting indicators according to the rigors of circular economy, the reporting addressing the average of the data obtained over the analyzed interval and presented in Table 2.
Figure 1. Inputs and outputs at the level of casting manufacturing.

Table 1. Quantities of materials included in the technological process and production of castings and the neutral part generated.

| Input / generated material                        | UM | Value  |
|--------------------------------------------------|----|--------|
| **MATERIAL ENTRIES IDENTIFIED IN THE TECHNOLOGICAL PROCESS** |    |        |
| For charging and making cast iron               | t  | 17,416 |
| For the preparation of forming mixtures          | t  | 7,096  |
| **For making molds**                            |    |        |
| For cleaning and sandblasting molds              | t  | 204    |
| For priming castings                            | t  | 27     |
| **For castings dispatch**                       |    |        |
| For making wooden models                        | m³ | 49     |
| Used to make metal models                       | m³ | 192    |
| **For making spare parts**                      |    |        |
| Used in equipment maintenance activities        | t  | 28     |
| Used for transport                              | t  | 139    |
| **TOTAL MATERIALS USED**                        | t  | 25,356 |
INPUT / GENERATED MATERIAL

VALUES

OUTPUTS IDENTIFIED FOLLOWING THE TECHNOLOGICAL PROCESS

| Material Description                                      | Unit | Value  |
|-----------------------------------------------------------|------|--------|
| Cast parts delivered                                      | t    | 15,713 |
| Recirculating cast iron (burrs, casting networks, scrap  | t    | 4,700  |
| parts, etc.)                                              |      |        |
| Metallic pellet waste                                     | t    | 1      |
| Ferrous cast iron chip                                    | t    | 839    |
| Ferrous steel iron chip                                   | t    | 10.0   |
| Aluminum waste                                            | t    | 0.5    |
| Cables                                                    | t    | 0.2    |

TOTAL MATERIAL WITH RECIRCULATION t 5,550.7

TOTAL MATERIALS WITH RECYCLING POTENTIAL t 5,565.1

TOTAL MATERIALS WITH NEUTRALIZATION TREATMENT t 27.7

TOTAL NON-USEFUL PART GENERATED 11,136.8

Table 2. Data on the production achieved and its reporting regarding environmental expenditures and investments made in the 2018 interval.

| Indicator                                                                 | Value of expenses, Euro | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | Annual average |
|--------------------------------------------------------------------------|-------------------------|-------|-------|-------|-------|-------|-------|-------|----------------|
| Electricity filtration installations                                      | 101,886                 | 188,088| 162,350| 152,681| 138,526| 124,361| 153,961| 145,979         |
| Household waste                                                          | 103,744                 | 2,763  | 3,347  | 5,892  | 6,213  | 8,188  | 7,110  | 19,608          |
| Hazardous waste                                                          | 5,767                   | 0      | 3,638  | 4,285  | 3,235  | 9,805  | 5,518  | 4,607           |
| Wastewater monitoring                                                    | 806                     | 1,914  | 2,330  | 11,054 | 2,459  | 1,067  | 286    | 2,845           |
| Monitoring environmental factors, Air                                    | 36,668                  | 5,456  | 5,283  | 4,954  | 4,631  | 4,408  | 4,520  | 8,709           |
| Sewage, household water                                                  | 36,753                  | 39,850 | 40,554 | 44,41  | 34,536 | 28,823 | 33,066 | 36,846          |
| Other environmental expenses                                             | 81                      | 52     | 48     | 41     | 39     | 9,192  | 38     | 1,356           |
| Total                                                                    | 158,095                 | 238,073| 217,550| 214,652| 189,641| 185,846| 204,501| 201,194         |
| Environmental investments                                                | 61,904                  | 35,346 | 116,518| 266,031| 0      | 122,146| 42,525 | 92,067          |
Table 3. Calculated values of the indicators related to the rigors of the circular economy.

| Indicator of reporting to the rigors of the circular economy                                                                 | UM | Value     |
|---------------------------------------------------------------------------------------------------------------------------|----|-----------|
| Mass recovery index at the level of castings (IVM)                                                                          | %  | 68.68     |
| The index of the non-useful part generated in the technological process (IPNU)                                              | %  | 64.14     |
| Index of the part with recirculation potential generated in the process of obtaining castings (IPPRECIRCULAR)              | %  | 31.86     |
| Index of the part requiring special disposal treatment (IPNTSE)                                                            | %  | 31.95     |
| Unit costs of electricity consumed in filtration plants €/1000 t of castings                                                |     | 26,231.62 |
| Unit costs on household waste management €/1000 t of castings                                                               |     | 3,523.45  |
| Unit costs for hazardous waste management €/1000 t of castings                                                              |     | 827.85    |
| Unit costs for wastewater monitoring €/1000 t of castings                                                                  |     | 511.23    |
| Unit costs for monitoring environmental factors €/1000 t of castings                                                        |     | 1,564.95  |
| Unit costs for wastewater management €/1000 t of castings                                                                  |     | 6,621.02  |
| Unit costs for other environmental costs €/1000 t of castings                                                              |     | 243.66    |
| Total unit environmental costs €/1000 t of castings                                                                         |     | 36,153.45 |
| Unitary investment for investments in the field of environmental protection €/1000 t of castings                            |     | 16,543.93 |

4. Interpretation of data obtained at the level of indicators from the perspective of the circular economy

The use of indicators in relation to the rigors of the circular economy gives us the possibility of some interpretations, which offers the possibility to determine the critical areas regarding the recalibration of the castings industry to the new requirements.

Thus, from the point of view of annual inputs and corresponding outputs, it is estimated that a ton of good castings is made - from a manufacturing point of view – out of 1.68 tons of materials specific to the technological process, which is a good capitalization of the resources introduced.

From the recirculation perspective, a first-rate process in building the circular economy, the value of the indicator is favorable to the process, in the sense that the manufacture of a ton of castings generates a quantity of 318 kilograms of materials that are recirculated in the technological process. Another interpretation, equally useful in ensuring the principles of the circular economy, is that there is a significant consumption of energy and material resources that is embedded in the networks of castings, processing additives and masses. Therefore, it is important that this indicator is as small as possible in order to reduce the consumptions mentioned. A drastic, technologically unprepared reduction can lead to a substantial increase in scrap, which requires a thorough increase in IT tools to ensure a secure design of manufacturing technology. From this perspective, it results that one of the measures to ensure the circular economy is related to the digitization of the castings industry.

Another element of ensuring the conditions of the circular economy is related to the knowledge of the non-useful part that has the potential to capitalize on recycling. Thus, the adopted indicator, which measures the weight of the process mentioned, at the level of the analysis it is found that for one ton of cast parts a quantity of 319.5 kg of materials is generated that have the potential to be capitalized at the level of recycling. In order to bring the process as close as possible to the circular economy it is important to have a reduction of the mentioned quantity, and for the entry in the recycling area to meet the related conditions it is important to refer to the specific by-product conditions. Therefore, in the entry into the recycling area of the non-useful part generated in the manufacture of castings, it is important to cooperate with other areas, especially with the area of building materials, public works and other sectors of the chemical industry and metallurgy. A relevant example in this field is the study,
carried out by two large French centers - CERIB and CTIF, which presents the results of the recovery of waste from the castings industry at the level of construction materials [8].

The fifth indicator gives us an image of the non-useful part, generated within the technological process, which requires a special neutralization treatment. In the case analyzed, it is found, as an average of the results processed in seven years, that for a ton of good cast parts it is necessary to neutralize a quantity of 16 kilograms, usually the materials that enter the hazardous zone. From the perspective of the circular economy, it is important that this amount is as small as possible.

At the level of indicators, which make an assessment of the expenditures made for ensuring the conditions of the circular economy, the importance of their knowledge is underlined. Given the fact that there are not enough data neither in the literature nor in the data which companies operate with, it is currently difficult to make a comparative analysis.

5. Conclusions
From the analysis of the existing situation for an average productive situation, in terms of ensuring technological developments, it is estimated that the success of including the manufacture of castings in the new rigors of the circular economy is not possible without establishing appreciation indicators, without cooperation with new fields of advanced engineering, which includes elements of intelligent informatics in ensuring the development and monitoring of the technological process.

The research carried out for a particular situation can be a model for analyzing the manufacturing process of castings, by referring to the requirements of the circular economy.

At the same time, there is a need to institutionalize the indicators of reporting to the circular economy and to stimulate the market economy of companies operating in the field of casting, from the perspective of efforts to ensure circularity for an industry that globally ensures a production of over 100 million tons.

6. References
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