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Material flow cost accounting analysis of twin-roll casting magnesium strips

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Abstract

Twin-roll casting is an energy-efficient technology for the magnesium strip production consisting of casting and rolling combined in one process step. Producing magnesium strips in an adequate quality-price ratio requires the application of material flow cost accounting to identify hidden improvement potentials. In the following, a material flow cost accounting analysis is carried out for the twin-roll casting process of AZ31 twin-roll-cast strips. Based on the findings, inefficient process steps of the twin-roll casting process are to be revealed, and actions for cost reduction from the point of a stable process management are to be assessed. Overall, an economic process and efficient material consumption can be designed for twin-roll casting considering the strip property development.

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Keywords: Twin-roll casting; Magnesium strips, Material flow cost accounting

1. Introduction

Value for money is an important criterion for the acceptance of magnesium components by Original Equipment Manufacturers for an industrial application. Beside external business process optimization in the context of supply chain quality individual process steps need to be further improved to achieve the required quality-price ratio [1].

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Especially in case of the twin-roll casting technology for the production of magnesium strips [2] the detection of saving potentials is considerable challenging. Compared with other production routes it is an economic and resource-saving procedure combining casting and rolling in one process step [3, 4].To realize additional cost savings, hidden material and energy inefficiencies need to be detected deriving measures for improvement. Supporting transparency of material and energy consumptions and its environmental and financial consequences material flow cost accounting is a useful tool to identify concealed inefficiencies [5, 6]. Therefore, the objective of this paper is to carry out a material flow cost accounting analysis for the twin-roll casting of magnesium AZ31 twin-roll-cast strips at the pilot plant of the Institute of Metal Forming at the TU Bergakademie Freiberg [7]. For this purpose, the twin-roll casting process is initially briefly described. Building on this, the material flow cost accounting analysis is conducted enabling a detailed view of all material and energy flows during twin-roll casting via material flow models. In the next step, the identified energy and material flows are illustrated as Sankey diagram proportional to their mass and energy content. To identify weak points, cost drivers and optimization potentials a material flow cost matrix was developed, whose results will be evaluated in this paper. Based on the technology's limitations appropriate improvement actions are proposed for further research.

2. Twin-roll casting process

Performing a material flow cost accounting analysis demands the understanding of the twin-roll casting process, which is illustrated in Fig. 1. To produce magnesium strips, ingots are melted in a furnace. The liquid magnesium alloy is routed by the casting channel to the casting nozzle, which pours the melt into the roll gap. By contact of the melt with the work rolls two shells build up and grow into each other till they are merged. At the same time the deformation is carried out. After leaving the roll gap the twin-roll-cast strip is trimmed and coiled [8]. Further information on the process is provided in the description of the input and output flows in the subsequent section.

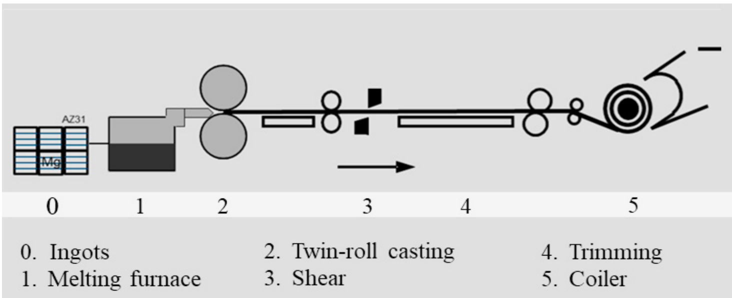

Fig. 1. Schematic illustration of twin-roll casting process based on [9].

3. Material flow cost accounting analysis of the twin-roll casting process

3.1. Methodology

Material flow cost accounting is a management instrument creating awareness and understanding of environmental and monetary effects of material and energy consumption in a chosen process [6,10,11]. The decision-supporting tool, which is standardized in ISO 14051:2011 [6], identifies environmental and cost-related optimization potentials [5,12]. It can be applied for all production processes and is not limited to twin-roll casting of magnesium. Steps required for implementing a material flow cost accounting analysis are build up in accordance with the Plan-Do-Check-Act cycle and are described in detail in [6]. They can be devided into three steps concerning flow structure modelling, quantification of flows and evaluation of material flows [13]. In the initial step, the system boundaries and time period are specified. Moreover, the quantity centers and their flows are determined. Quantity centers, i.e. a chosen process step or process steps, are defined depending on the level of detail of the material flow cost accounting analysis. The material flow model describing the considered system is the outcome of the first step. In the next step the material and energy streams are quantified in physical units for the underlying time period creating input-output balances for each quantity center. For the evaluation, the material and energy flows are quantified in monetary units. Finally, the data is summarized and interpreted via a material flow cost matrix. On the basis of the results optimization potentials are identified and evaluated [5,6,14].

3.2. Material flow cost accounting analysis of the twin-roll casting process

Foundation of the analysis is data gathered from experimental trials, which were performed under industrial conditions at the pilot plant of the Institute of Metal Forming at the TU Bergakademie Freiberg. The investigation is focused on the production of magnesium alloy AZ31 twin-roll-cast strips. The system boundaries of the material flow cost accounting analysis encompasses the twin-roll casting process of the pilot plant starting with melting magnesium AZ31 ingots up to coiling the strip. The presented quantity and cost data are based on numerical values that have been recorded over a longer period of time. It should be noted that maximum prices of resources and plant components for trial run operations were used for the analysis. Especially, the plant components are custom-made products and more cost-intensive in research operation. For modeling the material flows of the twin-roll casting process and generating the material flow cost accounting the software Umberto Efficiency+ [15] has been used which is based on the theoretical informatics concept of Petri-net systems to picture behavioral modeling [16]. Due to the fact that the production is divided into successive stages, four material flow models were developed providing a complete picture of the twin-roll casting process (see Fig. 2). They cover the fusion, ramp up, stable process and wind down phase.

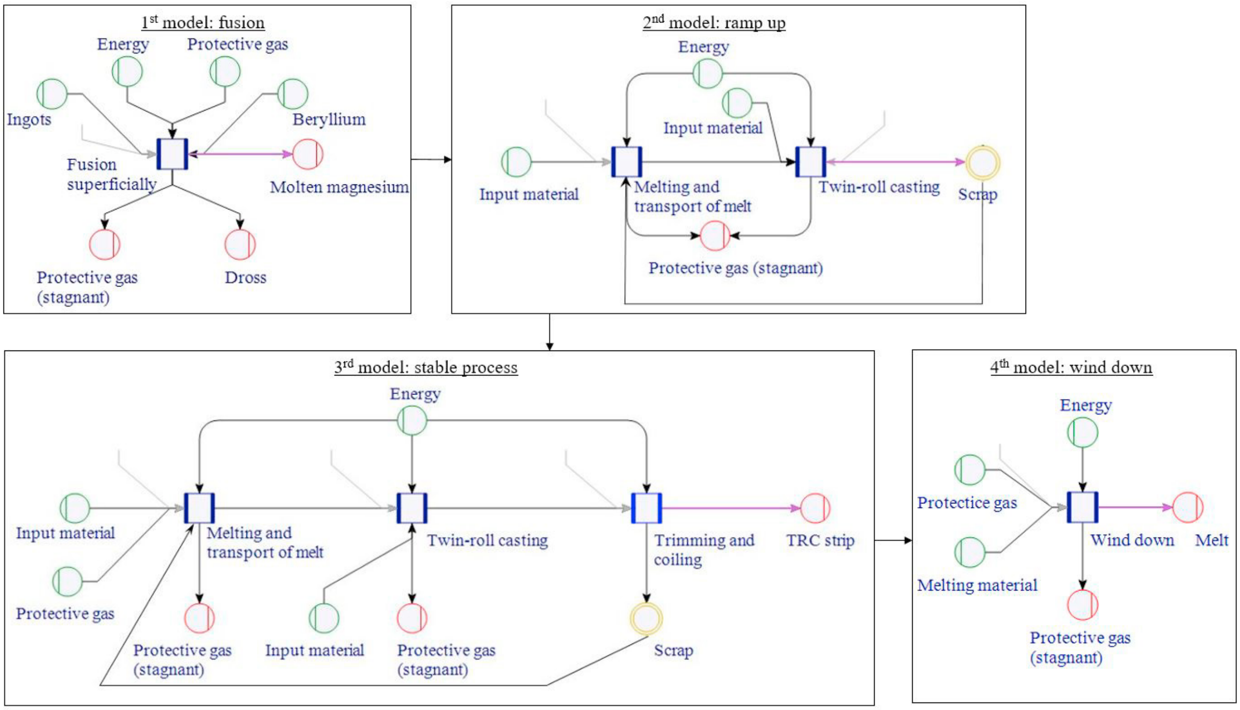

Fig. 2. Material flow models for twin-roll casting of AZ31 magnesium strips.

In terms of data preparation, the illustrated models will be explained separately in the following parts. The fusion phase (1st model) requires five hours and includes only the quantity center "fusion superficially". Main input material are AZ31 ingots, which are melted in a gas-fired melting furnace under protective gas (a combination of N_2 and a small amount of SF_6) and beryllium. Stirrer and thermocouples of the melting furnace are electrically-powered. During the melting process scabies are formed on the melt surface, which are removed, collected and disposed.

Modeling the ramp up phase (2nd model) two quantity centers were constructed including “melting and transport of melt” and “twin-roll casting”. In the first quantity center molten magnesium is kept at the required temperature in the melting furnace, which is further charged with a defined ratio of new magnesium ingots and recycling material (in-house scrap). Protective gas (N_2 and SF_6 mixture) counteracts the oxidation at the melt surface. Furthermore, the liquid magnesium alloy is transported from the melting furnace to the casting nozzle via casting channel, which is also heated electrically. In the second quantity center, the electrically heated steel casting nozzle casts the melt into the roll gap. During twin-roll casting, the work rolls are brushed, whose dust can be neglected due to the small amount. In the ramp up phase, only in-house scrap is produced until thermal stability is achieved. It is directly fed to the melting furnace.

Once the process has reached thermal stability, the transition to a stable process takes place (3rd model). The time frame of the stable process phase depends on the order quantity of coils influencing the mass and cost balance. The production of one coil with a weight of about 720 kilogram as output requires about 80 minutes. The corresponding material flow model composes the three quantity centers “melting and transport of melt”, “twin-roll casting” and “trimming and coiling”. The inputs and outputs of the first two process steps correspond to the previous model. During “trimming and coiling” the trimmed material is charged to the furnace. Throughout the removal of the produced twin-roll-cast strip from the coiler the production is continued by producing scrap sheets, which are burdened together with the accumulating trimming material to the melting furnace.

Completing the production process, the wind down phase (4th model) is realized within six hours and consists of only one quantity center, called “wind down”. The melt is slowly cooled down in the melting furnace and the largest bulk consumers are switched off. During these hours, a considerable amount of electrical energy and protective gas (mixture of N_2 and R-134a) is needed as further input. The solidified melt remains in the furnace until the next twin-roll casting campaign reducing the amount of new magnesium ingots in the subsequent trial.

Table 1 gives a brief overview of the required workers per model at the pilot plant. The execution workforce of the fusion, ramp up and wind down phase can be used for the stable process due to their chronological order.

Table 1. Workers in each model.

Model	Workers
Fusion	3
Ramp up	5
Stable process	4
Wind down	1

In the second step of the material flow cost accounting analysis the material and energy flows are quantified in physical units for each model, which is exemplarily illustrated for the stable process phase as Sankey diagram in Fig. 3. The arrow thickness shows the proportions to the quantity, which were not mentioned in this case for generalizing reasons.

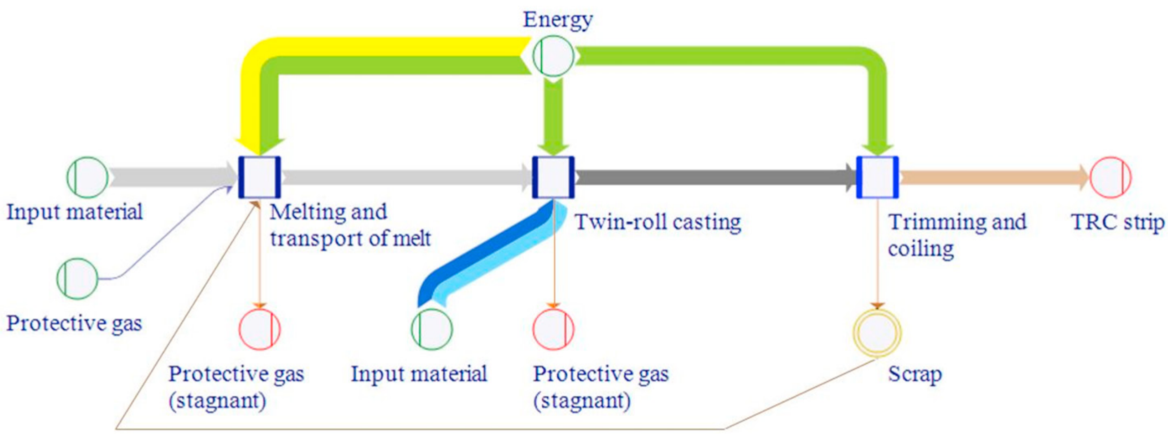

Fig. 3. Sankey diagram of stable twin-roll casting phase.

After the quantification of input and output flows in physical units, the monetary evaluation is realized to record the costs and revenues associated with the quantities. The difference between the material flow cost accounting analysis and conventional cost accounting methods is that the calculated costs are assigned to both product and material losses depending on their quantity. Thereby, a better overview can be achieved identifying inefficiencies and their costs. According to ISO 14051:2011 [6], cost types are typically differentiated into material costs, energy costs, system costs and waste management costs.

Material and energy costs are allocated directly to the respective material by Umberto Efficiency+ [15] and calculated.

System costs comprise labor and maintenance costs. Wages are calculated based on Table 1. Maintenance costs arise after a certain production volume requiring replacement of specific system components. As a result of thermal stress, the steel casting nozzle and the work rolls are such components. The nozzle has to be replaced after producing nine coils (approximately 6,500 kilogram) in trial run operations. A new nozzle costs about 15,000 euros (about 18,500 US dollars) for research facilities. Thus, it makes it one of the largest cost drivers. Work rolls must be grinded to ensure a regular thickness profile of the strip after 30 produced coils, which corresponds to approximately 21,500 kilogram of twin-roll-cast strip. In addition, the brushes and trimming shears are to be considered as wear parts, which also require a certain time interval for replacement. However, their costs are lower. In case of an industrial production, maintenance and replacement costs would be dramatically reduced because of the extended production time.

Disposal of scabies concerns waste management costs. Smaller amounts of waste such as tinsel or brushing dust can be neglected in the calculation like mentioned before. Scrap, resulting from trimming and discharging of the coil, are own scrap arisings, which are not considered as material losses. It will be fully re-melted and leads to the reduction of the amount of magnesium ingots during the melting process.

In the next step, the cost matrix per model is analyzed and evaluated. The biggest cost drivers during the fusion phase (1st model) are the material and labor costs. The reason is that 100 percent of magnesium ingots are melted at the beginning, while no recycling material is used to start the process for the first time.

Concerning the ramp up phase (2nd model), the new acquisition and commissioning of the steel casting nozzle causes the highest percentage of costs. Energy and system costs, however, are very low, which can be justified by the short operating time with a duration of one hour.

During the stable phase (3rd model), the material and system costs cause the highest expenditure because of the ratio of new magnesium ingots to produce twin-roll-cast strips and the labor expenses. It is guessed that the magnesium coil can be sold on the market for 4.50 euros (5.50 US dollar) per kilogram. So far, there is no defined price on the market for twin-roll-cast strips. Thus, the 4.50 euros were guided by the six euro per kilogram for ready-to sell hot rolled strips [17]. The price also depends on the magnesium ingots price.

Wind down (4th model) leads to the lowest costs of all four models. Note, protective gas as material costs and the energy costs is most expensive part in this phase.

Based on the material flow cost accounting analysis, the twin-roll casting process is identfied as a resource-efficient process. Main cost driver is the casting nozzle, where a high optimization potential exists.

To estimate the costs of the entire twin-roll casting process, all four models must be considered together. The costs incurred in the first, second and fourth model are not related to the production quantity of magnesium coils and thus remains unchanged. In order to present a meaningful result, the pilot plant is assumed as an industry-oriented continuous operation, which would produce 125 coils without interruption. This corresponds to a seven-days per week with 24 hours' shiftwork. The maintenance costs for the steel casting nozzle arise therefore only at the ramp up phase, whereas the regular research operation includes such costs after each three casting campaigns. Fig. 4 depicts the total expenses and the revenues per number of coils according to material flow cost accounting.

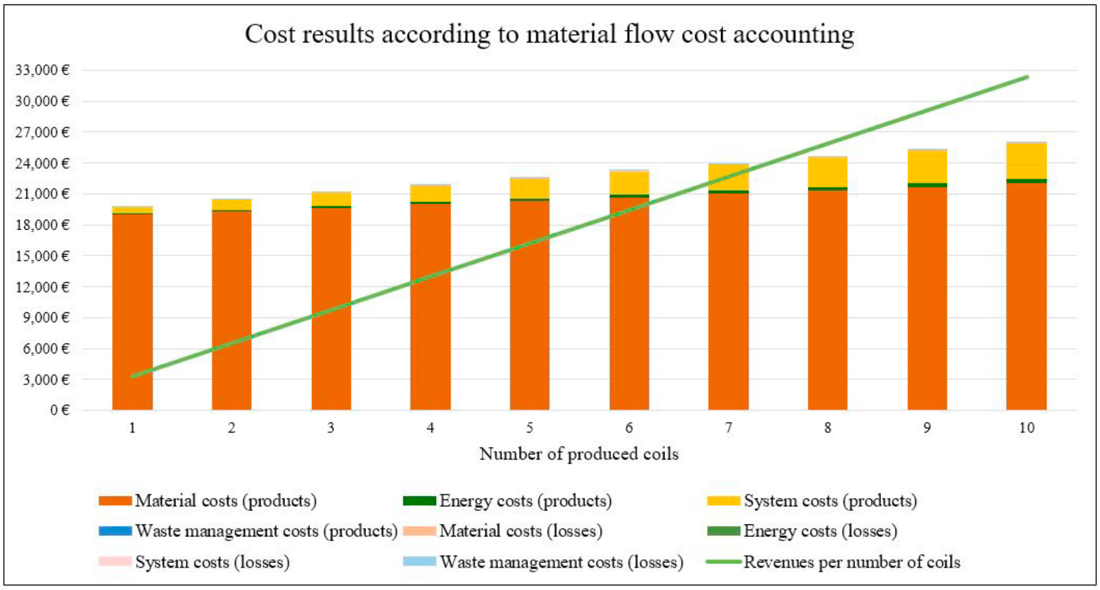

Fig. 4. Allocated costs and revenues per number of produced coils according to material flow cost accounting.

The results, which were calculated using a conventional cost accounting method are illustrated in Fig. 5

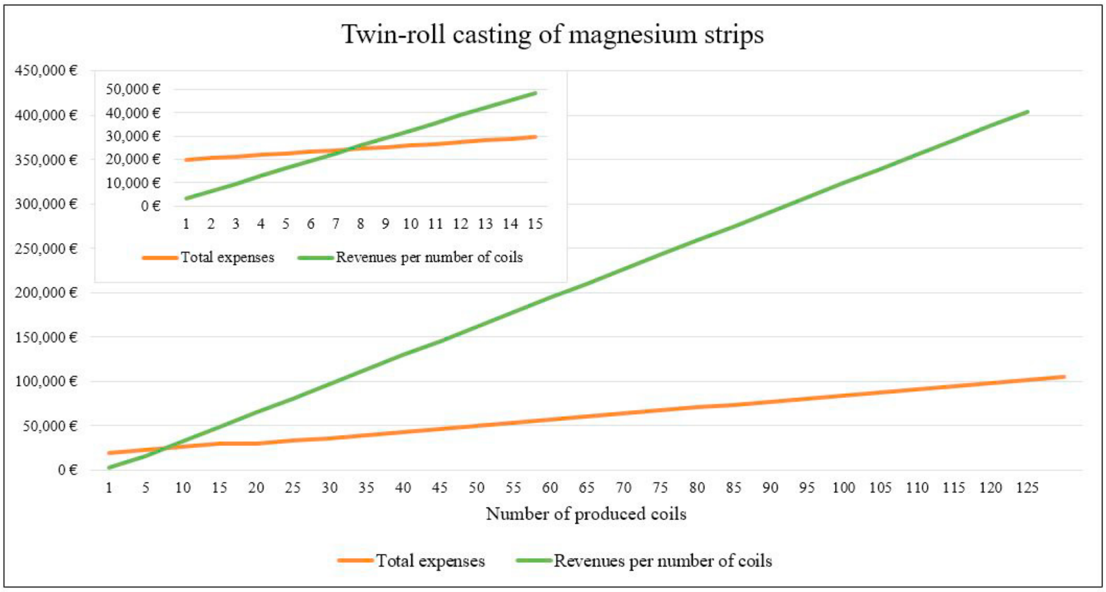

Fig. 5. Total expenses and revenues per number of coils calculated by the conventional cost accounting method.

The difference concerning the cost consideration underlines the advantageousness of material flow cost accounting toward the conventional method. For each produced coil and resulting material losses, a distinction between the four cost types, i.e. material costs, energy costs, system costs and waste management costs is undertaken (see Fig. 4). Therefore, it makes clear once again that the cost for materials is the largest cost factor in the production of magnesium strips followed by system costs. Summarising, the individual expenses for material costs, energy costs, system costs and waste management costs give the same total, as shown in Fig. 5. Comparing the revenues, we can conclude that twin-roll casting of magnesium strips will be profitable from the production of eight coils. Each additional produced coil leads to the rise of the profit, so that a profit of almost 400,000 euro (470,000 US dollar) can be expected after the production of 125 coils. These obtained results are considered as assumptions, which can be changed depending on the individual factors.

4. Conclusion and discussion

In this paper, a material flow cost accounting analysis was carried out for twin-roll casting of AZ31 twin-roll-cast strips. In this context, a valid model consisting of four submodels was developed to understand the environmental and financial effects of material and energy consumption. With respect to the results, it should be noted that the quantities and costs can only be applied to the pilot plant configuration. In addition peak prices were assumed and raw materials are subjected to fluctuations. In case of an industrial production, the consumptions and production costs will be further reduced based on extended production campaigns and quantity discounts for the required inputs. However, the results of the material flow cost accounting analysis illustrated that the twin-roll casting process is a resource-efficient and economic process despite short production runs. Moreover, it was shown how costs varied depending on the production volume.

To further optimize the twin-roll casting technology, the steel casting nozzle was identified as a major cost driver. Options to achieve a price reduction are on the one hand improved manufacturing processes of the casting nozzle and on the other hand the development of production strategies using ceramic nozzles.

Acknowledgements

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References

[1] C. Kawalla, M. Ligarski, M. Höck, Supply chain quality management for automotive components, forthcoming (2018).

[2] R. Kawalla, M. Oswald, C. Schmidt, M. Ullmann, H.P. Vogt, N.D. Cuong, New technology for the production of magnesium strips and sheets, Metalurgija, 47-3 (2008) 195–198.

[3] R. Kawalla, M. Ullmann, C. Schmidt, J. Dembińska, H.P. Vogt, Properties of magnesium strips produced by twin-roll-casting and hot rolling, MSF, 690 (2011) 21–24.

[4] M. Ullmann, F. Berge, K. Neh, R. Kawalla, Development of a rolling technology for twin-roll cast magnesium strips, Metalurgija, 54-4 (2015) 711–714.

[5] A. Schmidt, U. Götze, R. Sygulla, Extending the scope of material flow cost accounting – methodical refinements and use case, Journal of Cleaner Production, 108 (2015) 1320–1332.

[6] DIN (Deutsches Institut für Normung), Umweltmanagement - materialflusskostenrechnung - allgemeine rahmenbedingungen (ISO 14051:2011), Beuth Verlag GmbH, Berlin ICS 13.020.10, (2011).

[7] M. Oswald, C. Krbetschek, R. Kawalla, Technologieentwicklung zum gieß- und bandwalzen von magnesiumlegierungen, In: H.G. Bauer, W. Schadt (Eds.), Walzen von Flachprodukten, Springer Berlin Heidelberg, Berlin, Heidelberg, (2017) 40–59.

[8] C. Kawalla, M. Hoeck, Quality assurance system for hot rolled TRC magnesium strips, Scientific Papers of Silesian University of Technology. Organization and Management Series, 100 (2017) 171–179.

[9] A. Nam, U. Prüfert, M. Eiermann, R. Kawalla, Modelling the temperature evolution during hot reversing strip rolling of magnesium alloys, Materials Science Forum, 854 (2016) 140–145.

[10] M.B. Fakoya, H.M. van der Poll, Integrating ERP and MFCA systems for improved waste-reduction decisions in a brewery in South Africa, Journal of Cleaner Production, 40 (2013) 136–140.

[11] C. Kasemset, J. Chernsupornchai, W. Pala-ud, Application of MFCA in waste reduction: Case study on a small textile factory in Thailand, Journal of Cleaner Production, 108 (2015) 1342–1351.

[12] M. Schmidt, The interpretation and extension of Material Flow Cost Accounting (MFCA) in the context of environmental material flow analysis, Journal of Cleaner Production, 108 (2015) 1310–1319.

[13] R. Sygulla, A. Bierer, U. Götze, Material flow cost accounting, proposals for improving the evaluation of monetary effects of resource saving process designs, In: Proceedings of the 44th CIRP Conference on Manufacturing Systems, (2011).

[14] A. Schmidt, B. Hache, U. Götze, Material flow cost accounting with umberto, In: R. Neugebauer, U. Götze, W.G. Drossel (Eds.), Energetisch-wirtschaftliche Bilanzierung und Bewertung technischer Systeme – Erkenntnisse aus dem Spitzentechnologiecluster eniPROD: 1. und 2. Methodenworkshop der Querschnittsarbeitsgruppe 1 „Energetisch-wirtschaftliche Bilanzierung“ des Spitzentechnologieclusters eniPROD, Verlag Wissenschaftliche Scripten, (2013) 231–247.
[15] Umberto Efficiency +, ifu Institut für Umweltinformatik Hamburg GmbH.
[16] V. Wolgemuth, A. Bock, Theoretischer hintergrund, In: V. Wolgemuth, A. Bock (Eds.), Einsatz der Software UMBERTO in angewandter Forschung und Praxis: Anwendungsfälle und Praxisbeispiele des UMBERTO Competence Centers Berlin, Aachen, (2012).
[17] G. Kurz, S. Pakulat, J. Bohlen, D. Letzig, Rolling twin roll cast magnesium strips with varied temperature and degree of deformation, Conference MEFORM 2015, Light Metals – Forming Technologies and Further Processing, Freiberg, (2015).