Use of technical and economic analysis in production of liquid metal in foundries

V. Kafka a, V. Figala b, V. Nykodýmová b, M. Herzán c, Z. Sypták c, B. Pělucha d

a doc. Ing. Václav Kafka, CSc., Racio & Racio, Orlová-Lutyně, Czech Republic
b Ing. Václav Figala, Foundry department, FMME, VSB – Technical University Ostrava, Czech Republic
b Ing. Veronika Nykodýmová, Foundry department, FMME, VSB – Technical University Ostrava, Czech Republic
c Miroslav Herzán, KRÁLOVOPOLSKÁ SLÉVÁRNA, Ltd., Brno, Czech Republic
c Ing. Zdeněk Sypták, KRÁLOVOPOLSKÁ SLÉVÁRNA, Ltd., Brno, Czech Republic
d Ing. Břetislav Pělucha, METALEX, Ostrava, Czech Republic

* Corresponding author: E-mail: vaclav.kafka@iol.cz

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Abstract

The paper in its introduction describes main principles of technical and economic analysis the application of which leads to determination of potential costs savings and subsequently to costs reduction. The application of the method is illustrated by an example of production of three types of steel grades for cast steel produced in five tons electric arc furnace. With the aid of the calculation model, incomplete costs of selective complex of the melts were determined (30 melts within the first phase and 260 in the second one). Incomplete costs and selected physical indicators (e.g. melting time, electrical energy consumption etc.) were subsequently compiled with the aid of statistical analysis. After that, the individual selective complexes were compared with each other (according to melters; first and second melt on the shift; melting with one or more charge basket; days in a week). The detailed analysis of these outcomes resulted in many particular recommendations how to reduce the costs in the foundry. The final recommendation for the melting shop is a proposal to introduce continuous monitoring of costs.

Keywords: Technical and economic analysis, Selective complex, Incomplete costs

1. Introduction

In the introduction, the article focuses on main reasons of technical and economic analysis. Moreover, there is an outline of results of the first phase of technical and economic analysis applied in KRÁLOVOPOLSKÁ SLÉVÁRNA, Ltd.

1.1 Reasons for technical and economic analysis

The main aim of the technical and economic analysis in foundries is to mark potential costs savings in particular technological, energy, and organizational suboperation. Subsequent detailed solution of the costs savings indicated by the analysis in an exactly concretized field of a melting process, could lead to cost savings. Generally speaking, by using this method we could consider the whole melting process which could consist of n suboperations. Direct suggestion for follow-up investigation on the basis of this analysis could occur for three suboperations only. Furthermore, we will obtain projection of possible potential costs savings of these suboperations. Of course, after a detailed investigation of the marked suboperation, we will not manage to reduce costs by the indicated possible amount. Figuratively speaking, we are in a situation in which we consider power of a car. By using the above mentioned method we conclude that problem solving A will be reached by increase by X %. A problem solving B will increase the power by Y %. Other problem solving will bring us no significant asset.
Existing approach to monitoring of cost decrease in most foundries is not so complex what could result in disproportional cost drain. Moreover, fields in which significant cost reduction could be calculated might be overlooked. The goal of classic approaches for cost reduction in foundries usually consists of:

a) reduction of human resources;
b) attempt to buy cheaper material;
c) reduction of an amount of consumed energy (electrical energy, gas etc.);
d) reduction of steady costing units by increase of production etc.

1.2. Continuation in previous results of technical and economic analysis

The article tries to follow up the first phase of technical and economic analysis of 30 melts of grades internally marked GS34CfMo4 in conditions of KRÁLOVOPOLSKÁ SLÉVÁRNA, Ltd., in Czech Republic. Results of this phase implied that there are significant possibilities for costs savings virtually in all considered areas. The items were measured as follows:

a) total incomplete working costs of production of liquid metal;
b) metal charge and metallic ingredient costs;
c) processing costs;

Obtained results of the analysis indicated possible remedies, especially in areas as follows:

a) optimization of metal compound ingredients;
b) consideration of the influence of different metal usage;
c) influence of different energy regimes;
d) optimization of procedures.

A decision was made for specification of these signals to extend previous 30 melts to a complex of approximately 300 melts. Thus, in the second phase there were 260 melts considered according to three different grades.

2. Principles of technical and economic analysis

The applied production process is considered in order to find a way to costs reduction and in the same time with preserving all its of functions. For this purpose the production process will be represented by selective complexes of melts (made by neutral indexes) which enables costs evaluation. Selective complexes, e.g. when considering production of liquid phase, are formed by individual melts, when preparing moulding materials they consist of individual operations of mixing partial components, when producing salamander casting they are formed by cast sequences and so on.

When assorting costs units of selective complexes we calculate so that the following is possible:

a) To determine the costs of the whole production process results and its partial phases (e.g. a ton of liquid phase in its splitting for melting, oxidation etc.);
b) To compare the determined costs of the product according to:
   1. different teams;
   2. work shifts;
   3. weekdays;
   4. different time periods (months in year etc.).
c) Afterwards, the chosen costs and natural indicators are statistically analyzed. This means that expected values, variability and reproducibility indexes are specified. In the same way the mathematical dependences between the chosen costs and natural indicators are searched. The bases are supplemented with graphical parts (histograms of frequency, tables of frequency intervals, etc.).

All of the prepared data serve for choosing of costs differences when producing the product in partial phases by selected teams, work shifts, etc. Having documented the import of calculated costs differences they serve for further examination (to shorten the melting time during steel production in an electric arc furnace) [1].

3. Subject of processing

260 melts of three different steel grades were the subjects of the second phase of technical and economic analysis in conditions of KRÁLOVOPOLSKÁ SLÉVÁRNA, Ltd. These grades were internally marked 35NCD6V, 11120D2N, and 17220D2N, and they were evaluated in second half of 2007.

3.1. 35NCD6V steel grade

According to a French standard the grade is marked as 35NCD6V. It is low-alloy with additions of chrome, nickel and molybdenum.

This steel grade contains C 0.3 – 0.38 %, Cr 1.4 – 1.7 %, Ni 1.4 – 1.7 %, Mo 0.15 – 0.35 %.

This steel grade is destined for highly strained machine components (huge cogwheels). The hardening capacity is increased, so that it is possible to use it for heavy machine parts. 30 melts of this grade were measured.

3.2. 11120D2N steel grade

According to the DIN 17 182 standard the grade is marked GS-20Mn5N (1.1120). We are talking about low-alloy manganese steel with better weldability.

This steel grade contains C 0.17 – 0.23 %, Mn 1 – 1.5 %.

This structural steel is produced to be used in lower temperatures (in annealed state up to ~ 20 °C). 70 melts were measured of this grade.

3.3. 17220D2N steel grade

According to the DIN 17 182 standard the grade is marked GS-34CrMo4 (1.17220) by the DIN 17 205 standard. It is low-alloy steel with chrome and molybdenum additions.
This steel grade contains C 0.3 – 0.37 %, Cr 0.8 – 1.2 %, Mo 0.2 – 0.3 %.

This steel is destined to use for greatly strained machine parts (cogwheels). 160 melts of this grade were measured.

4. Technical and economic analysis in practice

Methodology of the analysis consisted at first in costs calculation of separate melts of each above mentioned steel grades. Afterwards, they were divided into selective complexes (according to melters, charge baskets, melts, weekdays etc.) Then the chosen selective complexes of costs and natural indicators were evaluated with the aid of statistical analysis methods.

4.1. Composition of the costs model

The costs model of production of three different steel grades was composed on the basis of calculation of incomplete working costs. It takes into account all costs that are linked with the production of each of the steel grades made in electric arch furnaces in the conditions of KRÁLOVOPOLSKÁ SLÉVARNA, Ltd.

The costs model evaluates:

a) total incomplete costs for production of liquid metal;

b) metal charge costs;

c) metallic ingredients costs;

d) metal charge costs and metallic ingredients costs;

e) non-metallic ingredients costs;

f) metal charge costs, metallic and non-metallic ingredients costs;

g) processing costs (graphite electrodes, personal costs, electric energy consumption, lining lid costs, furnace lining costs, metal analysis and temperature measure costs).

The model also covers:

a) number of melts on the lid, number of melts per a lining, number of charge baskets

b) weight of molten metal

c) melting usage of metal

d) temperature of steel (of the metal, at beginning of casting)

e) time (of the whole process of melting, of the separate melting)

f) final analysis of liquid metal.

4.2. Specification of a selective complex

Each of the above mentioned steel grades forms one main selective complex of melts. Main selective complexes are further divided in partial selective complexes if needed. E.g., for comparison of molten metal production costs between A and B melters the main selective complex of melts was divided according to melters.

4.2.1. Selective complex 35NCD6V

It is a selective complex of 30 melts that was statistically evaluated as a whole and subsequently divided in relation with melters. 6 melts were examined in the selective complex of the melter A, 24 melts in case of the melter B.

4.2.2. Selective complex 11120D2N

The selective complex 11120D2N with frequency of 70 melts was first of all subjected to statistical analysis as a whole. Afterwards, for purposes of statistical analysis it was split up in relation with melters, number of charge baskets and the melts order on the shifts. In the selective complex 20 melts were investigated of the melter A and 50 ones the melter B. Furthermore, 49 melts charged in one charge basket and 21 melts charged in two charge baskets. Statistical evaluation of 39 melts followed. These ones were melted as first on the shift and further 31 melts came after.

4.2.3 Selective complex 17220RV1

This selective complex of 160 melts was at first examined as a complex. A division according to melters, charge baskets, melting orders and weekdays then followed. Such vast selective complex (160 melts) enabled its division into a tree diagram as well. This diagram represents partitions of the selective complex into partial selective complexes (Fig. 1).

![Fig. 1. Partition of the selective complex into the tree diagram](image)

This kind of diagram is very useful when studying huge amount of selective complexes. In such situation we can split the main selective complex into many partial units, which are enough for objective statistical analysis.

4.3. Statistical analysis of the selective complex

The statistical analysis consisted in evaluation of partial selective complexes by using chosen statistical indexes. These
indexes were used as criteria for a detailed consideration of separate costs and natural indexes linked with the production of liquid metal.

The following statistical indexes were used:

a) minimum and maximum value of selected complex;
b) mean values (arithmetic mean, median);
c) variability indexes (standard deviation, range, variation coefficient);
d) upper and lower limits of confidence intervals of means.

Besides these indexes, each of the selective complexes was measured graphically as well. We used these methods:

a) frequency histograms;
b) confidence intervals of means;
c) boxplots.

4.4. Evaluation of results

Due to huge amount of processing data, it was decided to use for this article a certain partial selective complex only. 79 melts of the 17220RV1 grade were chosen. They were 79 first melts in the shifts charged of one charge basket in relation with the melter (A or B). We evaluated total incomplete working costs invested in production of liquid metal. We continued in the evaluation of metal charge costs and metallic ingredients costs.

4.4.1. Evaluation of incomplete working costs

As can be see from Tab. I. the total incomplete working costs of molten metal production range from 13,226 to 19,296 CZK/ton (Tab. I., line 3, columns 3, 4). Mean TIWC reach 15,687 CZK/ton of molten metal (Tab. I., line 3, column 5). The TIWC of the melter B run to 14,642 CZK/ton of molten metal in average that is by 1,965 CZK/ton less than in case of the melter A. We conclude that the melter B spends by 1,965 CZK/ton less in production of molten metal than the melter A. At the same time he spends by 1,045 CZK/ton less of the IWC than the total average.

Tab. I.
Statistical indexes of the TIWC

<table>
<thead>
<tr>
<th>Selective complex of melts</th>
<th>Number of melts</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Arithmetic mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>[-]</td>
<td>[CZK/ton]</td>
<td>[CZK/ton]</td>
<td>[CZK/ton]</td>
<td>[CZK/ton]</td>
</tr>
<tr>
<td>1 Melter A</td>
<td>42</td>
<td>13,753</td>
<td>19,296</td>
<td>16,607</td>
<td>16,622</td>
</tr>
<tr>
<td>2 Melter B</td>
<td>37</td>
<td>13,226</td>
<td>17,119</td>
<td>14,642</td>
<td>14,560</td>
</tr>
<tr>
<td>3 ∑</td>
<td>79</td>
<td>13,226</td>
<td>19,296</td>
<td>15,687</td>
<td>15,369</td>
</tr>
</tbody>
</table>

Basically, histograms of frequency in Figs. 2. and 3. confirm the facts calculated in Tab. I. The highest number of melts of the melter A ranges from 16,000 to 17,000 CZK/ton of the IWC. On the other hand, the highest number of the melter B was concentrated in the range from 15,000 to 16,000 and less CZK/ton of the IWC.

Fig. 2. Histogram of TIWC frequency, melter A

Fig. 3. Histogram of TIWC frequency, melter B

Such results of this calculation are considered to be statistically significant. They are found both on detailed figures in Tab. II., and on confidence intervals of means of the IWC represented in Fig. 4.

Tab. II.
Confidence intervals of means of the TWIC

<table>
<thead>
<tr>
<th>Selective complex of melts</th>
<th>Lower limit</th>
<th>Upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>[CZK/ton]</td>
<td>[CZK/ton]</td>
</tr>
<tr>
<td>1 Melter A</td>
<td>16,162</td>
<td>17,052</td>
</tr>
<tr>
<td>2 Melter B</td>
<td>14,350</td>
<td>14,934</td>
</tr>
<tr>
<td>3 ∑</td>
<td>15,340</td>
<td>16,033</td>
</tr>
</tbody>
</table>

The TIWC invested on production of liquid metal range from 15,340 to 16,033 CZK/ton with 95 per cent probability. The IWC of the melter B range from 14,350 to 14,934 CZK/ton (Tab. II., line 2, columns 2, 3). As for the melter A, his confidence intervals of means of the IWC range from 16,162 to 17,052 CZK/ton (Tab. II., line 1, column 2, 3). It is evident that confidence intervals of means of the TIWC of the A and B melters miss each other. That means that results are objective.

Fig. 4. Confidence intervals of means of the TIWC
We conclude that when the melter B is producing liquid metal of 17220RV1 grade (first melt, one charge basket), the costs produced by him are by 13 per cent in average lower than that ones of the melter A.

Such outcomes beg the question of what is the cause of difference in the TIWC when producing liquid metal in relation with melters. The analysis of metal charge costs and metallic ingredients costs as well as analysis of processing costs help us to find the cause. The above mentioned costs form important part of the TIWC.

4.4.2 Evaluation of metal charge and metallic ingredients costs

At first, we focused on measurement of material costs (metal charge and metallic ingredients costs). These two types of costs form the biggest part of the TIWC when producing liquid metal of the 17220RV1 grade. We can suppose that reduction of these costs will contribute to significant reduction of the TIWC.

As we can see from Tab. III., total metal charge and metallic ingredients costs reach 13,241 CZK/ton of liquid metal in average (line 3, column 5). The costs of the melter B amount to 12,157 CZK/ton of liquid metal (Tab. III., line 2, column 5). On the other hand, the melter’s A costs are 14,196 CZK/ton (Table 3, line 1-2, column 5) more effective than the melter A. The measured deviation is surprisingly higher than the difference, which was reached by the comparison of the TIWC of both melters (1,965 CZK/ton). When calculating further costs related with production of liquid metal we find areas in which the second melter is more effective. That is the melter B.

Tab. III.

<table>
<thead>
<tr>
<th>Selective complex of melts</th>
<th>Number of melts</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Arithmetic mean</th>
<th>Median</th>
<th>Mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[CZK/ton]</td>
<td>[CZK/ton]</td>
<td>[CZK/ton]</td>
<td>[CZK/ton]</td>
<td>[CZK/ton]</td>
<td></td>
</tr>
<tr>
<td>Melter A</td>
<td>1</td>
<td>42</td>
<td>11,337</td>
<td>17,043</td>
<td>14,196</td>
<td>12,157</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>37</td>
<td>10,722</td>
<td>17,733</td>
<td>12,175</td>
<td>14,196</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>79</td>
<td>10,722</td>
<td>17,043</td>
<td>12,241</td>
<td>12,157</td>
</tr>
<tr>
<td>Melter B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data given in Tab. IV. and Fig. 5. actually depict reality, i.e. the melter B works with lower metal charge and metallic ingredients costs.

Tab. IV.

<table>
<thead>
<tr>
<th>Selective complex of melts</th>
<th>Confidence intervals of means</th>
<th>Arithmetic mean</th>
<th>Confidence intervals of means</th>
<th>Arithmetic mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower limit</td>
<td>Upper limit</td>
<td>Lower limit</td>
<td>Upper limit</td>
</tr>
<tr>
<td></td>
<td>[CZK/ton]</td>
<td>[CZK/ton]</td>
<td>[CZK/ton]</td>
<td>[CZK/ton]</td>
</tr>
<tr>
<td>Melter A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>14,633</td>
</tr>
<tr>
<td></td>
<td>13,759</td>
<td>14,633</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melter B</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11,870</td>
<td>12,443</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From Fig. 5. it is evident that when evaluating the confidence intervals of means of charge and metallic ingredients costs in relation with melters the costs ranges do not overlap each other. This outcome is likewise statistically important as well.

4.4.3 Evaluation of processing costs

The second phase of finding the causes of the difference of TIWC between melters consisted in the analysis of processing costs. At first the total processing costs were calculated. It has been found out that the total costs difference of both melter’s processing costs is not so significant at first glance, as when
Calculating the metal charge and metallic ingredients costs. As regards the material costs, the melter’s A processing costs are lower than those ones of the melter B. The difference amounts to 55 CZK/ton of liquid metal (Tab. VI., line 1, 2, column 2). At first glance it might seem that there is small possibility of costs reduction. The preliminary caution principle pushes us to focus on further dealing with this item.

Under the terms of processing costs, labour costs, repair lining costs and electrical energy were calculated. In our case, selective items of processing costs are influenced by melting time (labour costs, lining costs and graphite electrodes) and by electrical energy consumption (graphite electrodes). Thus, we will be dealing only with these natural items [2].

At first, costs items were measured in proportion of melting time. When comparing melting times of the A and B melters it was found out that the melter’s A melting time is by 12 minutes shorter in average than that one of the melter B (Tab. VI., line 1, 2, column 3). This outcome is confirmed by confidence intervals of means which do not overlap. The melter’s A melting time ranges from 198 to 207 minutes, while the melter’s B one ranges from 209 to 219 minutes. Consequently, we focused on investigation of melting time which represents approximately two thirds of the whole melting time.

It follows from Tab. VI. that the difference in melting times between two teams is 5 minutes (line 1, 2, column 4). Based on confidence intervals of means the average melting time of the melter A ranges from 132 to 141 minutes while the average melting time of the melter B ranges from 137 to 146 minutes. The intervals of reliability do overlap, i.e. the results are not so obvious as in the case of melting time.

Nevertheless, the shorter time consumption of the melter A in relation with the whole melting time is indicated. For the given reasons we obtain further outcome of the analysis, i.e. the recommendation of detailed investigation of melting time organization.

Tab. VI.
The selected indexes characterizing processing procedure of steel melting in an electric arc furnace

*the melting metal usage is figured in kg/ton lowered by 1000

<table>
<thead>
<tr>
<th>Selective complex of melts</th>
<th>Cost of processing</th>
<th>Melting time</th>
<th>Melting time</th>
<th>El. energy consumption</th>
<th>Melting metal usage*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As mean</td>
<td>As mean</td>
<td>As mean</td>
<td>As mean</td>
<td>As mean</td>
</tr>
<tr>
<td></td>
<td>[CZK/ton]</td>
<td>[min]</td>
<td>[min/meltage]</td>
<td>[kWh/ton]</td>
<td>[Kg/ton]</td>
</tr>
<tr>
<td>Units</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>1. Melter A</td>
<td>2,262</td>
<td>202</td>
<td>138</td>
<td>828</td>
<td>109</td>
</tr>
<tr>
<td>2. Melter B</td>
<td>2,317</td>
<td>214</td>
<td>141</td>
<td>846</td>
<td>95</td>
</tr>
<tr>
<td>3. Y</td>
<td>2,288</td>
<td>208</td>
<td>139</td>
<td>837</td>
<td>97</td>
</tr>
</tbody>
</table>

In relation with energy regimes we focused on electrical energy comparison of both melters. The measured deviation between the A and B melters amounts to 18 kWh/ton of liquid metal (Tab. VI., line 1, 2, column 5). Further on it is evident from the analysis that the electrical energy consumption range is very extensive. The melter’s A consumption range reaches to 333 kWh/t while the melter’s B one runs to 297 kWh/t. We conclude that the electrical energy consumption varies in allocation. This indicates the use of different energy regimes what is another reason for investigation of electrical energy consumption in the foundry.

Costs of others selective complexes were calculated in the same way.

5. Conclusion

It can be concluded that the second phase of technical and economic analysis in conditions of KRÁLOVOPOLSKÁ SLÉVÁRNA, Ltd., was made in which 260 melts of three different grades were tested. Such complex enabled us to compare costs in relation with first and second melts on the shift, mutual costs comparison of teams. Moreover, we were able to compare melting costs charged by one or two charge baskets, costs comparison in particular weekdays, etc.

Outcomes of this investigation virtually confirmed the existence of costs savings which were indicated by the first phase. For the foundry itself it is important as follows:

a) to deal with metallurgical regimes (potential costs savings 1,925 CZK/ton, expected savings of 650 CZK/ton per selected grade)
b) to investigate the shortage of melting time (expected asset 6 minutes)
c) to solve out different energy regimes, melting metal usage, number of metal analysis, etc.

On the basis of detailed evaluation of reached outcomes, the foundry is recommended to suggest an introduction of model costs for continuous monitoring costs of the selected condition of EAF. It should ensure costs outcome of each melt, to analyze it and to recommend a change in the following melts.

In further phases of melting it is expected to use results of the artificial intelligence, gained in the grant project.

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Literature