TECHNICAL AND ECONOMIC STUDY ON LANDMARKS FROM A.D.I.

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Abstract
The paper presents an experimental study regarding the obtaining of 3 landmarks for the automotive industry, made from 4 alloyed Austempered Ductile Irons (A.D.I.) and made a technical and economic study aiming to achieve maximum benefit, from using the 3 landmarks. For this process were used in the following specifications: A.D.I. materials, the specific amount of materials (T1-T4) treated daily for achieving the landmarks (L1, L2, L3), quantity available of A.D.I. materials, using the calculation of Simplex algorithm - the One Phases’ Method.

Keywords: Cast irons, heat treatment, A.D.I., linear programming, optimization

Introduction
Austempered Ductile Iron (A.D.I.) with a bainitic matrix, obtained by heat treatment and isothermal hardening is the material which combines a lot of superior attributes of the classical cast iron or forged iron (Harding, 2007), being in a serious competition with the iron used by the moment in the automotive industry (Rimmer, 2004).

Another benefit of ADI material’s advantages over steel is its lower density, which may influence a higher mass efficiency, or similar mass efficiency at lower cost.

Earlier papers (Simon, 1996) have shown what a major importance represents the studies about the bainitic S.G. cast irons obtained by heat treatment, especially the isothermal hardening (Batra et. al., 2003).

After this heat treatment, the structure is composed of ferrite and bainite (in the case of cast iron, the bainite mean a structure composed of bainitic ferrite and carbon enriched austenite). The structures confer to material high values for the impact strength even at the low temperature (Eric et. al., 2006).
Research objectives
This research have an important objective, to made a technical and economic study aiming to achieve maximum benefit, from using the 3 landmarks for the automotive industry, made by 4 alloyed A.D.I. materials.

Materials
The studied cast iron has the following chemical composition (% in weight), presented in table 1.

<table>
<thead>
<tr>
<th>Cast irons type</th>
<th>Chemical compositions, [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Type 1</td>
<td>3.70</td>
</tr>
<tr>
<td>Type 2</td>
<td>3.48</td>
</tr>
<tr>
<td>Type 3</td>
<td>3.75</td>
</tr>
<tr>
<td>Type 4</td>
<td>3.75</td>
</tr>
</tbody>
</table>

This cast iron was made in an induction furnace. Nodular changes were obtained with the "In mold" method, with the help of prealloy FeSiMg with 10-16% Mg, added into the reaction chamber in a proportion of 1.1% of the treated cast iron.

The structure in raw state for all 4 type of A.D.I. was perlito-feritic typical for a cast iron with geometrically regular nodular form.

Heat treatments
The parameters of the heat treatment for all 4 type of cast irons was the following:
- the austenizing temperature was, $t_A = 900[^{\circ}\text{C}]$ for lots A, B and C;
- the maintained time at austenizing temperature was, $\tau_A = 30$ [min];
- the temperature at isothermal level was $t_{iz} = 300[^{\circ}\text{C}]$
- the maintained time at the isothermal level was, $\tau_{iz} = 60$ [min].

All these 4 experimental lots were performed at isothermal maintenance in salt-bath, being the cooling after the isothermal maintenance was done in air.

The structure of the Austempered ductile iron (ADI) with a bainitic matrix, obtained by heat treatment and isothermal hardening was bainitic ferrite, high carbon austenite and graphite nodules. Martensite, ferrite, iron carbides and other alloy carbides may also be present.

Experimental results
In this experiment it was intended to study the obtaining of 3 landmarks used in automotive industry, special alloys products (A.D.I. materials). For this process were used in the following specifications: A.D.I. materials, the amount of heat treated landmarks daily, quantity available of
A.D.I. materials, aiming to achieve maximum benefit, data presented in Table 2. For solving the optimization problem using the Simplex algorithm - the One Phases’ Method (Taloi, 1987).

In Optimization of Industrial Unit Processes, the term "optimization" means the maximizing of productivity and safety while minimizing operating costs (Klemes et. al., 2011).

Klem. In a fully optimized plant, efficiency and productivity are continuously maximized while levels, temperatures, pressures, or flows float within their allowable limits (Anderson, 2006).

The optimization criteria in this case is economic nature, so the function is an objective indicator of economic efficiency of the process analyzed (Barbu et. al., 2008).

Simplex algorithm applies when the number of equations (m) and number of variables (n) is large and full description of the method is cumbersome (Deb, 2001).

Steps for optimization by using a linear programming are:
(1) Enter experimental data;
(2) Establish the objective function;
(3) Establish the restrictions problem (functional conditions of the process);
(4) Establish the non negative conditions;
(5) Establishment of linear canonical program (CLP);
(6) Perform linear canonical transformation program (CLP) in the standard linear program (SLP);
(7) Finding the solution to start, solving equation;
(8) Determination of the base variables (BV) and the values of base variables (VBV).
(9) Simplex table is built, starting by iteration 0;
(10) Calculating basic changes (iterations);
(11) When the optimum is determined, calculation stops and the values of optimum are displayed;

The presentation of the input data for this experimental calculation is presented in table 2.

<table>
<thead>
<tr>
<th>ADI materials</th>
<th>The specific amount of materials (T1-T4) treated daily for achieving the landmarks (L1, L2, L3), [t]</th>
<th>Quantity available, [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 (T1)</td>
<td>0.52                                                             1.19                                                             1.11                                                             62</td>
<td></td>
</tr>
<tr>
<td>Type 2 (T2)</td>
<td>0.74                                                             0.21                                                             1.03                                                             47</td>
<td></td>
</tr>
<tr>
<td>Type 3 (T3)</td>
<td>0.23                                                             0.83                                                             1.02                                                             58</td>
<td></td>
</tr>
<tr>
<td>Type 4 (T4)</td>
<td>0.75                                                             1.01                                                             1.14                                                             53</td>
<td></td>
</tr>
<tr>
<td>Benefit, [Euro]</td>
<td>5075                                                             9500                                                             11700                                                            -</td>
<td></td>
</tr>
</tbody>
</table>

Analyzing Table 2 mentions the following:
- the specific amount of materials (T1-T4) treated daily for achieving the landmark, L1, it consists of: 0.52 t (type 1), 0.74 t (type 2), 0.23 t (type 3), 0.75 t (type 4), brings a benefit of 5075 Euro;
- the specific amount of materials (T1-T4) treated daily for achieving the landmark, L2, it consists of: 1.19 t (type 1), 0.21 t (type 2), 0.83 t (type 3), 1.01 t (type 4), brings a benefit of 9500 Euro;
- the specific amount of materials (T1-T4) treated daily for achieving the landmark, L3, it consists of: 1.11 t (type 1), 1.03 t (type 2), 1.02 t (type 3), 1.14 t (type 4), brings a benefit of 11700 Euro;

**Calculation steps for optimization by using a linear programming**

The steps of the classical calculation are:

1) Establishment of linear canonical program (CLP)

a) The objective function (function to be optimized is the Benefit):

\[ F = 5075x_1 + 9500x_2 + 11700x_3 = \text{max} \]  

(b) The restrictions of the problem are:

\[
\begin{align*}
0.52 x_1 + 1.19x_2 + 1.11x_3 & \leq 62 \\
0.74 x_1 + 0.21x_2 + 1.03x_3 & \leq 47 \\
0.23 x_1 + 0.83x_2 + 1.21x_3 & \leq 58 \\
0.75 x_1 + 1.01x_2 + 1.14x_3 & \leq 53
\end{align*}
\]  

(c) Non negativity conditions:

\[ x_1 \geq 0 ; x_2 \geq 0 ; x_3 \geq 0 \]  

2) Perform linear canonical transformation program (CLP) in the standard linear program (SLP) by adding or subtracting (depending on the shape of each inequality, in our case, \(\leq\)) of variable spacing (\(x_{ie}\)) variables are added in this care in order to easily get value system (for finding the solution to start).

a) The objective function is given by the equation (1)

b) The restrictions of the problem become:

\[
\begin{align*}
0.52 x_1 + 1.19x_2 + 1.11x_3 + x_{1e} & = 62 \\
0.74 x_1 + 0.21x_2 + 1.03x_3 + x_{2e} & = 47 \\
0.23 x_1 + 0.83x_2 + 1.21x_3 + x_{3e} & = 58 \\
0.75 x_1 + 1.01x_2 + 1.14x_3 + x_{4e} & = 53
\end{align*}
\]  

c) The non negativity conditions become:

\[ x_1 \geq 0 ; x_2 \geq 0 ; x_3 \geq 0 ; x_{1e} \geq 0 ; x_{2e} \geq 0 ; x_{3e} \geq 0 ; x_{4e} \geq 0 \]  

3) The determining of the base variables (BV) and the values of base variables (VBV), presented in table 3.

| Table 3. Base variables (BV) and values of base variables (VBV) |
|-------------------|---|
| BV                | VBV |
| \(x_{1e}\)        | 62  |
| \(x_{2e}\)        | 47  |
| \(x_{3e}\)        | 58  |
| \(X_{4e}\)        | 53  |
The values from VBV are considered to be an admissible basic solution [1];
4) Simplex table is built, starting by iteration 0 (iteration= changing of base), presented in table 4.

<table>
<thead>
<tr>
<th>c_j</th>
<th>BV</th>
<th>VBV</th>
<th>x_1e</th>
<th>x_2e</th>
<th>x_3e</th>
<th>x_4e</th>
<th>x_1</th>
<th>x_2</th>
<th>x_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>x_1e</td>
<td>62</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.52</td>
<td>1.19</td>
<td>1.11</td>
</tr>
<tr>
<td>0</td>
<td>x_2e</td>
<td>47</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.74</td>
<td>0.21</td>
<td>1.03</td>
</tr>
<tr>
<td>0</td>
<td>x_3e</td>
<td>58</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0.23</td>
<td>0.83</td>
<td>1.02</td>
</tr>
<tr>
<td>0</td>
<td>x_4e</td>
<td>53</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.75</td>
<td>1.01</td>
<td>1.14</td>
</tr>
</tbody>
</table>

Because is an maximum program optimization, it was analyzed all different x_j - c_j
- establish a procedure that allows moving from one base to another;
- basic changes are made by decreasing values (problem solved is maximum) optimization function;
- stops the iteration process (moving from one base to another), when it is not possible to increase the value of optimization function.
- enter the base, the x_3 variable and x_2e variable is out of the base;

In Table 5 is presented the Simplex table, phase I, iteration 1

<table>
<thead>
<tr>
<th>c_j</th>
<th>BV</th>
<th>VBV</th>
<th>x_1e</th>
<th>x_2e</th>
<th>x_3e</th>
<th>x_4e</th>
<th>x_1</th>
<th>x_2</th>
<th>x_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>x_3e</td>
<td>11.35</td>
<td>1</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>-0.28</td>
<td>0.96</td>
<td>1.11</td>
</tr>
<tr>
<td>11700</td>
<td>x_3</td>
<td>45.63</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0.72</td>
<td>0.20</td>
<td>1.03</td>
</tr>
<tr>
<td>0</td>
<td>x_3e</td>
<td>11.46</td>
<td>0</td>
<td>-</td>
<td>1</td>
<td>0</td>
<td>-0.50</td>
<td>0.62</td>
<td>1.02</td>
</tr>
<tr>
<td>0</td>
<td>x_4e</td>
<td>0.98</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>-0.07</td>
<td>0.78</td>
<td>1.14</td>
</tr>
</tbody>
</table>

Because is an maximum program optimization, it was analyzed all different x_j - c_j and enter the base, the x_2 variable and x_4e variable is out of the base;

In Table 6 is presented the Simplex table, phase I, iteration 2

<table>
<thead>
<tr>
<th>c_j</th>
<th>BV</th>
<th>VBV</th>
<th>x_1e</th>
<th>x_2e</th>
<th>x_3e</th>
<th>x_4e</th>
<th>x_1</th>
<th>x_2</th>
<th>x_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>x_1e</td>
<td>10.13</td>
<td>1</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-0.19</td>
<td>0</td>
<td>1.11</td>
</tr>
<tr>
<td>11700</td>
<td>x_3</td>
<td>45.37</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>0.74</td>
<td>0</td>
<td>1.03</td>
</tr>
<tr>
<td>0</td>
<td>x_3e</td>
<td>10.67</td>
<td>0</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-0.45</td>
<td>0</td>
<td>1.02</td>
</tr>
<tr>
<td>9500</td>
<td>x_2</td>
<td>1.26</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-0.09</td>
<td>1</td>
<td>1.14</td>
</tr>
</tbody>
</table>

z_j = 542855.54
z_j - c_j = 0
Because all differents \( z_j - c_j \geq 0 \), so it reached the optimal (maximum) solution. The mathematical results of the optimal solutions are:

\[
z_0 = F_{\text{max}} = 542855.54, \text{ with solutions:}
\]

\[
x_2 \text{ optimum} = x_2 = 1.26, \\
x_3 \text{ optimum} = x_3 = 45.37;
\]

**Conclusion:**

Analyzing all data taken into account, there can say the following:

(a) In this experiment it was studied the obtaining of 3 landmarks used in automotive industry, special alloys products (A.D.I. materials).

(b) For this process were used in the following specifications: A.D.I. materials, the amount of heat treated landmarks daily, quantity available of A.D.I. materials, aiming to achieve maximum benefit, using the Simplex algorithm - the One Phases’ Method.

(c) The mathematical results of the optimal solutions of this application are: the benefit is 542855.54 Euro, producing landmarks, L2 (1.26 t, treated daily) and L3 (45.37 t, treated daily);

(d) Regarding the landmark L1, it can be achieved depending on production requirements, it is not taken into account to achieve maximum benefit.

**References:**


