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

Ioan Milosan, PhD
Professor, Transilvania University of Brasov, Romania

Abstract

The paper presents an experimantal 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. 1: Chemical composition of the studied cast iron

Cast irons type	Chemical compositions, [%]							
	C	Si	Mn	P	S	Mg	Mo	Cr
Type 1	3.70	2.18	0.40	0.013	0.004	0.055	-	0.35
Type 2	3.48	2.16	0.38	0.012	0.003	0.070	-	0.18
Type 3	3.75	2.14	0.40	0.012	0.003	0.050	0.15	-
Type 4	3.75	2.14	0.41	0.014	0.004	0.050	0.21	-

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[°C] for lots A, B and C;
- the maintained time at austenizing temperature was, τ_A = 30 [min];
- the temperature at isothermal level was t_{iz} = 300[°C]
- the maintained time at the isothermal level was, τ_{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 2: The presentation of the input data

ADI materials	The specific amount of materials (T1-T4) treated daily for achieving the landmarks (L1, L2, L3), [t]			Quantity available, [t]
	L1 (x_1)	L2 (x_2)	L3 (x_3)	
Type 1 (T1)	0.52	1.19	1.11	62
Type 2 (T2)	0.74	0.21	1.03	47
Type 3 (T3)	0.23	0.83	1.02	58
Type 4 (T4)	0.75	1.01	1.14	53
Benefit, [Euro]	5075	9500	11700	-

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):

$$F = 5075x_1 + 9500x_2 + 11700x_3 = \max \quad (1)$$

b) The restrictions of the problem are:

$$\begin{cases} 0.52\,x_1 + 1.19x_2 + 1.11x_3 \le 62 \\ 0.74\,x_1 + 0.21x_2 + 1.03x_3 \le 47 \\ 0.23\,x_1 + 0.83x_2 + 1.21x_3 \le 58 \\ 0.75\,x_1 + 1.01x_2 + 1.14x_3 \le 53 \end{cases} \quad (2)$$

c) Non negativity conditions:

$$x_1 \ge 0\,;\ x_2 \ge 0\,;\ x_3 \ge 0 \quad (4)$$

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, $\le$) 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:

$$\begin{cases} 0.52\,x_1 + 1.19x_2 + 1.11x_3 + x_{1e} = 62 \\ 0.74\,x_1 + 0.21x_2 + 1.03x_3 + x_{2e} = 47 \\ 0.23\,x_1 + 0.83x_2 + 1.21x_3 + x_{3e} = 58 \\ 0.75\,x_1 + 1.01x_2 + 1.14x_3 + x_{4e} = 53 \end{cases} \quad (5)$$

c) The non negativity conditions become:

$$x_1 \ge 0\,;\ x_2 \ge 0;\ x_3 \ge 0;\ x_{1e} \ge 0\,;\ x_{2e} \ge 0;\ x_{3e} \ge 0;\ x_{4e} \ge 0; \quad (6)$$

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 4. Simplex Table, Phase I, Iteration 0

c_J / c_i	BV	VBV	0	0	0	0	5075	9500	11700
			x_{1e}	x_{2e}	x_{3e}	x_{4e}	x_1	x_2	x_3
0	x_{1e}	62	1	0	0	0	0.52	1.19	1.11
0	x_{2e}	47	0	1	0	0	0.74	0.21	1.03
0	x_{3e}	58	0	0	1	0	0.23	0.83	1.02
0	x_{4e}	53	0	0	0	1	0.75	1.01	1.14
	z_j	0	0	0	0	0	0	0	0
		$z_j - c_j$	0	0	0	0	- 5075	- 9500	- 11700

Because is an maximum program optimization, it was analyzed all differents $z_j - c_j$

- 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 5. Simplex Table, Phase I, Iteration 1

c_J / c_i	BV	VBV	0	0	0	0	5075	9500	11700
			x_{1e}	x_{2e}	x_{3e}	x_{4e}	x_1	x_2	x_3
0	x_{1e}	11.35	1	-	0	0	- 0.28	0.96	1.11
11700	x_3	45.63	0	-	0	0	0.72	0.20	1.03
0	x_{3e}	11.46	0	-	1	0	- 0.50	0.62	1.02
0	x_{4e}	0.98	0	-	0	1	- 0.07	0.78	1.14
	z_j	533883.5	0	-	0	0	8405.83	2385.44	11700
		$z_j - c_j$	0	-	0	0	3330.83	-7114.56	0

Because is an maximum program optimization, it was analyzed all differents $z_j - c_j$ 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 6. Simplex table, phase I, iteration 2

c_J / c_i	BV	VBV	0	0	0	0	5075	9500	11700
			x_{1e}	x_{2e}	x_{3e}	x_{4e}	x_1	x_2	x_3
0	x_{1e}	10.13	1	-	0	-	- 0.19	0	1.11
11700	x_3	45.37	0	-	0	-	0.74	0	1.03
0	x_{3e}	10.67	0	-	1	-	- 0.45	0	1.02
9500	x_2	1.26	0	-	0	-	- 0.09	1	1.14
	z_j	542855.54	0	-	0	-	7774.23	9500	11700
		$z_j - c_j$	0	-	0	-	2699.23	0	0

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

$z_0 = F_{max} = 542855.54$, with solutions:

$x_{2\ optimum} = x_2 = 1.26$;,

$x_{3\ optimum} = x_3 = 45.37$;

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 solutins 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:

Anderson, C., G. Applied metallurgical process testing and plant optimization with design of experimentation software. Minerals, Metals & Materials Society, part I, 1-26, 2006.

Babu, B., V., Angira, R., Optimization of Industrial Proceses Using Improved and Modified Differential Evolution, Springer-Verlag, Berlin, 2008.

Batra, U., Ray, S. and Prabhakar, SR. Effect of austenitization on austempering of copper alloyed ductile iron, Journal of Material Engineering and Performance, v. 12, n. 5, p. 597-601, 2003.

Deb, K. Multi-objective optimization using evolutionary algorithms, John Wiley & Sons, Chichester, 2001.

Eric, O., Rajnovic, D., Zec, S., Sidjanin, L., Jovanovic, M. T. Microstructure and fracture of alloyed austempered ductile iron, Materials Characterization, Vol. **57**, No. 4-5, p. 211-217, 2006.

Harding, R.A. The production, properties and automotive applications of austempered ductile iron, Kovove Materialy, Vol. 45, p. 1-16, 2007.

Klemes, J., Friedler, F., Bulatov, I., Varbanov, P. Sustainability in the Process Industry: Integration and Optimization, Green Manufacturing & Sistem Engineering, Manchester, 2011.

Rimmer, A. ADI solutions aid vehicle design, The Foundry Trade Journal, March, p. 54-56, 2004.
Simon, D. ADI- a new material for the automotive engineer, Foundry Trade J., 2, p. 66-67, 1996.
Taloi, D. Optimization of metallurgical processes. Application in metalurgy, E.D.P. Bucharest, 1987.