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Computer-aided control of high-quality cast iron

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Abstract

The study discusses the possibility of control of the high-quality grey cast iron and ductile iron using the author's genuine computer programs. The programs have been developed with the help of algorithms based on statistical relationships that are said to exist between the characteristic parameters of DTA curves and properties, like $R_{p0,2}$, R_m, A_5 and HB. It has been proved that the spheroidisation and inoculation treatment of cast iron changes in an important way the characteristic parameters of DTA curves, thus enabling a control of these operations as regards their correctness and effectiveness, along with the related changes in microstructure and mechanical properties of cast iron. Moreover, some examples of statistical relationships existing between the typical properties of ductile iron and its control process were given for cases of the melts consistent and inconsistent with the adopted technology.
A test stand for control of the high-quality cast iron and respective melts has been schematically depicted.

Keywords: High-quality cast iron; DTA; Control

1. Introduction

To be able to assess the alloy quality before pouring of foundry moulds is of primary importance for the successful process of making castings. Knowing the properties of castings still before their manufacture enables us to avoid missed melts, rejects caused by improper metal quality, as well as laborious and expensive laboratory examinations and control tests made on the ready product. The quality control can be easier and more effective using genuine computer programs assigned for monitoring of alloy behavior. Programs of this type were designed by the Chair of Materials Engineering and Production Systems of the Technical University of Lodz [1-22]. Computer programs control and assist the melting process of high-quality metal alloys, operating within the range of physico-chemical properties available in liquid state and predicting the future mechanical and physical properties that the alloys are expected to offer while in solid state. In their structure, the programs are based on a derivative thermal analysis (DTA). The characteristic parameters of the alloy cooling and solidification curves serve as a starting point for the development of statistical relationships between these curves, the alloy chemical composition and the required utilization properties of castings, e.g. $R_{p0,2}$, R_m, A_5, HB, etc. The relationships are an essential element in construction of algorithms for computer programs of molten metal control

2. Methods of research

A stand for computer-aided control of high-qaulity cast iron in depicted in Figure 1.

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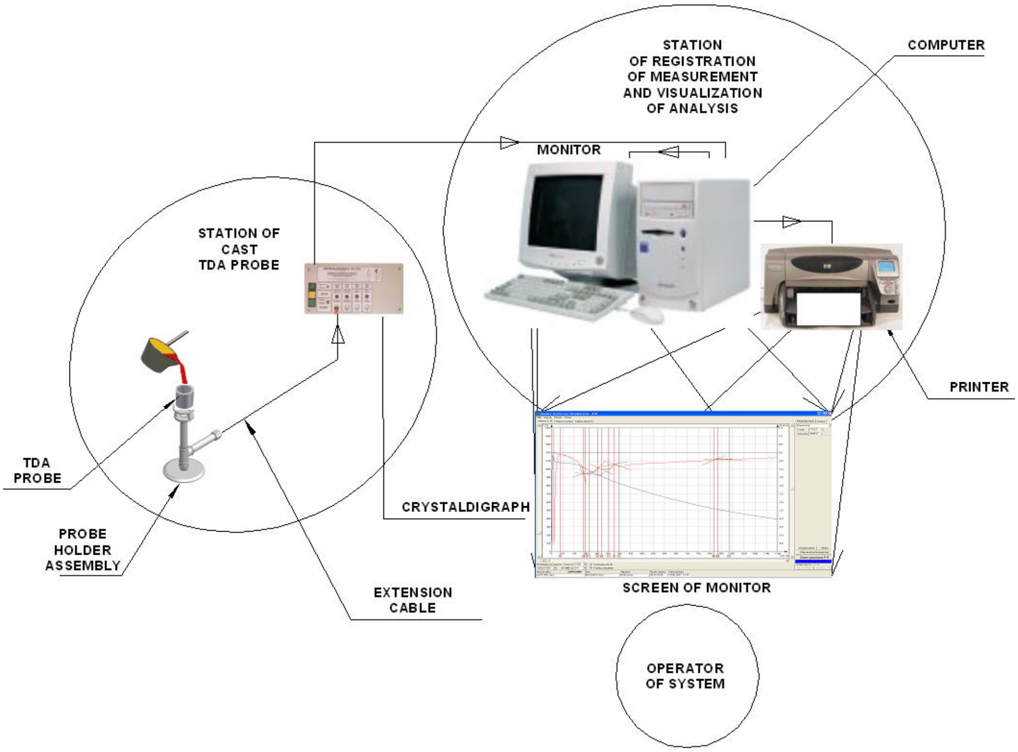


Fig. 1. Schematic representation of a stand for computer-aided control of high-quality cast iron

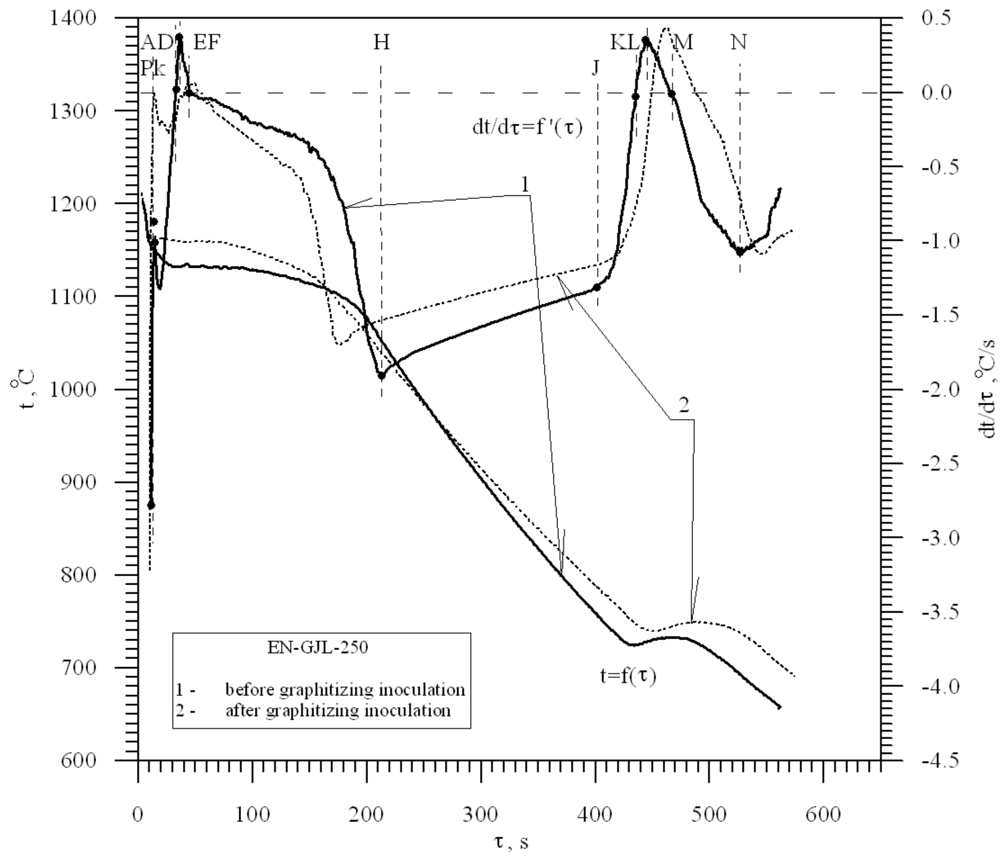
The stand is provided with a Crystalldigraph apparatus which records changes of metal temperature in time, i.e. t=f(τ), and computes the first derivative after time, i.e. dt/dτ=f(τ). A signal to Crystalldigraph is transmitted by a PtRh10-Pt or NiCr-Ni thermocouple, the second terminal of which has been fixed in a tripod. The tripod holds a DTA probe with quartz pipe, which is put on the thermocouple. On pouring of metal into a probe, the electric signal is transmitted through the thermocouple to a Crystalldigraph, wherefrom it passes to computer which processes the received information, plotting two curves: a cooling curve [t=f(τ)] and a solidification curve [dt/dτ=f(τ)]. Both curves are displayed on the monitor; they can also be printed on a printer.

3. The results

The DTA curves of grey cast iron, grade EN-GJL-250, before and after inoculation with SB5 inoculant are shown in Figure 2. From the diagram it follows that before inoculation the cast iron is hypoeutectic; the crystallisation of its eutectic is proceeding at a slower rate, lower temperature and over a longer period of time than after the inoculation. The austenite→pearlite transformation also takes place at a lower temperature but in a shorter span of time. After the treatment of graphitising inoculation, the cast iron becomes hypereutectic, the eutectic crystallisation point raises, the time of the crystallisation is reduced, and the rate of its growth raises. In a like manner, also the temperature of the austenite→pearlite transformation increases and it becomes longer in duration.

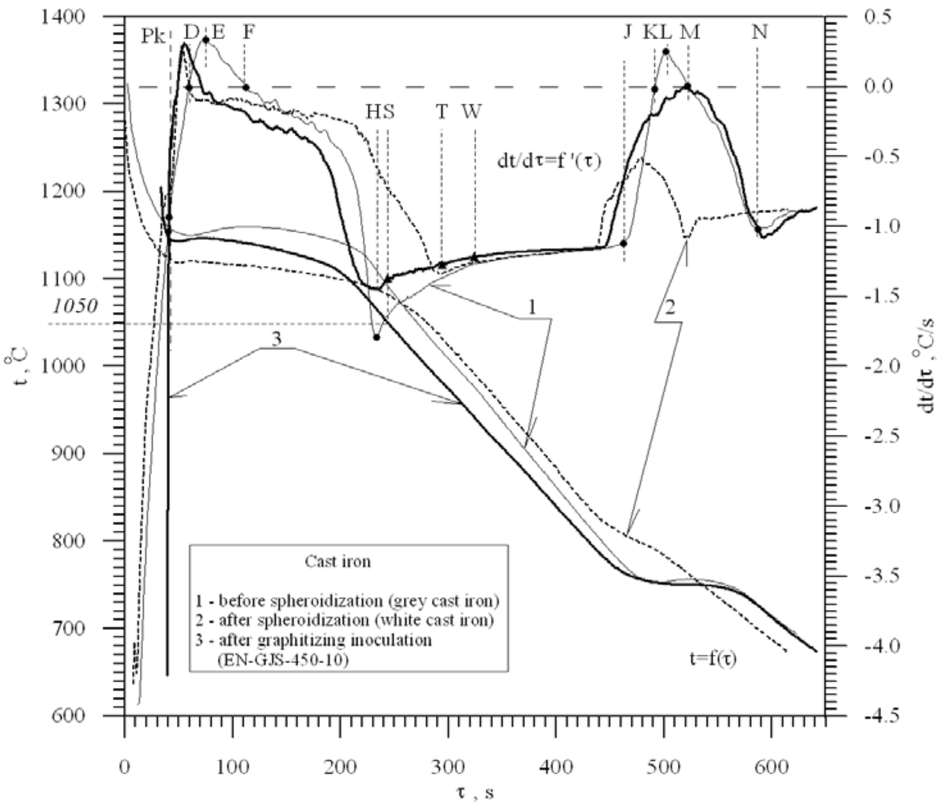
Figure 3 shows the DTA curves of base cast iron assigned for spheroidization with magnesium and the same cast iron after magnesium spheroidisation and graphitising inoculation.

Some significant differences occur in the DTA curves after each successive treatment. The spheroidising treatment of cast iron with magnesium, resulting in its solidification in metastable system, prolongs the time of ledeburite eutectic crystallisation and, compared with base cast iron, reduces the temperature and crystallisation rate. The eutectoid transformation takes place at the highest temperature and in the shortest span of time. After graphitising inoculation of cast iron, the temperature of eutectic crystallisation is comprised between the eutectic temperature of base cast iron and that of cast iron after spheroidisation, the crystallisation rate is the highest and the crystallisation time - the shortest. The temperature of eutectoid transformation is similar to the base cast iron but time of its duration is the longest.



Temperature	t, °C		Δt, °C
	Before graphitizing inoculation	After graphitizing inoculation	Δt=(2)-(1)
	1	*2*	
t_A	1150	1164	14
t_D	1132	1159	27
t_F	1134	1159	25
t_F-t_D	2	0	-2
t_H	1052	1095	47
t_J	758	782	24
t_K	725	740	15
t_M	733	749	16
t_M-t_K	8	9	1
t_N	693	717	24
Time	τ, s		Δτ, s
			Δτ=(2)-(1)
$\tau_{KP}=\tau_H-\tau_{Pk}$	202	164	-38
$\tau_{KW}=\tau_N-\tau_J$	126	143	17

Fig. 2. DTA curves of grey cast iron, grade EN-GJL-250, before and after inoculation



Temperature	t, °C			Δt_1=(2)-(1)	Δt_2=(3)-(1)	Δt_3=(3)-(2)
	Before spheroidization	After spheroidization	After graphitizing inoculation	°C		
	1	*2*	*3*			
t_D	1150	1118	1143	-32	-7	25
t_F	1160	1120	1147	-40	-13	27
t_F-t_D	10	2	4	-8	-6	2
t_H	1111	1032	1065	-79	-46	33
t_J	773	833	778	60	5	-55
t_K	752	799	751	47	-1	-48
t_M	757	799	751	42	-6	-48
t_M-t_K	5	0	0	-5	-5	0
t_N (t_L)	728	762	721	34	-7	-41
Time	τ, s			$\Delta\tau_1$=(2)-(1)	$\Delta\tau_2$=(3)-(1)	$\Delta\tau_3$=(3)-(2)
				s		
$\tau_{KP}=\tau_H-\tau_{Pk}$	193	254	164	61	-29	-90
$\tau_{KW}=\tau_N-\tau_J$ ($\tau_{KW}=\tau_L-\tau_J$)	125	88	144	-37	19	56

Fig. 3. DTA curves of base cast iron assigned for spherodization and the same cast iron after this treatment and inoculation (the cast iron of EN-GJS-450-10 grade)

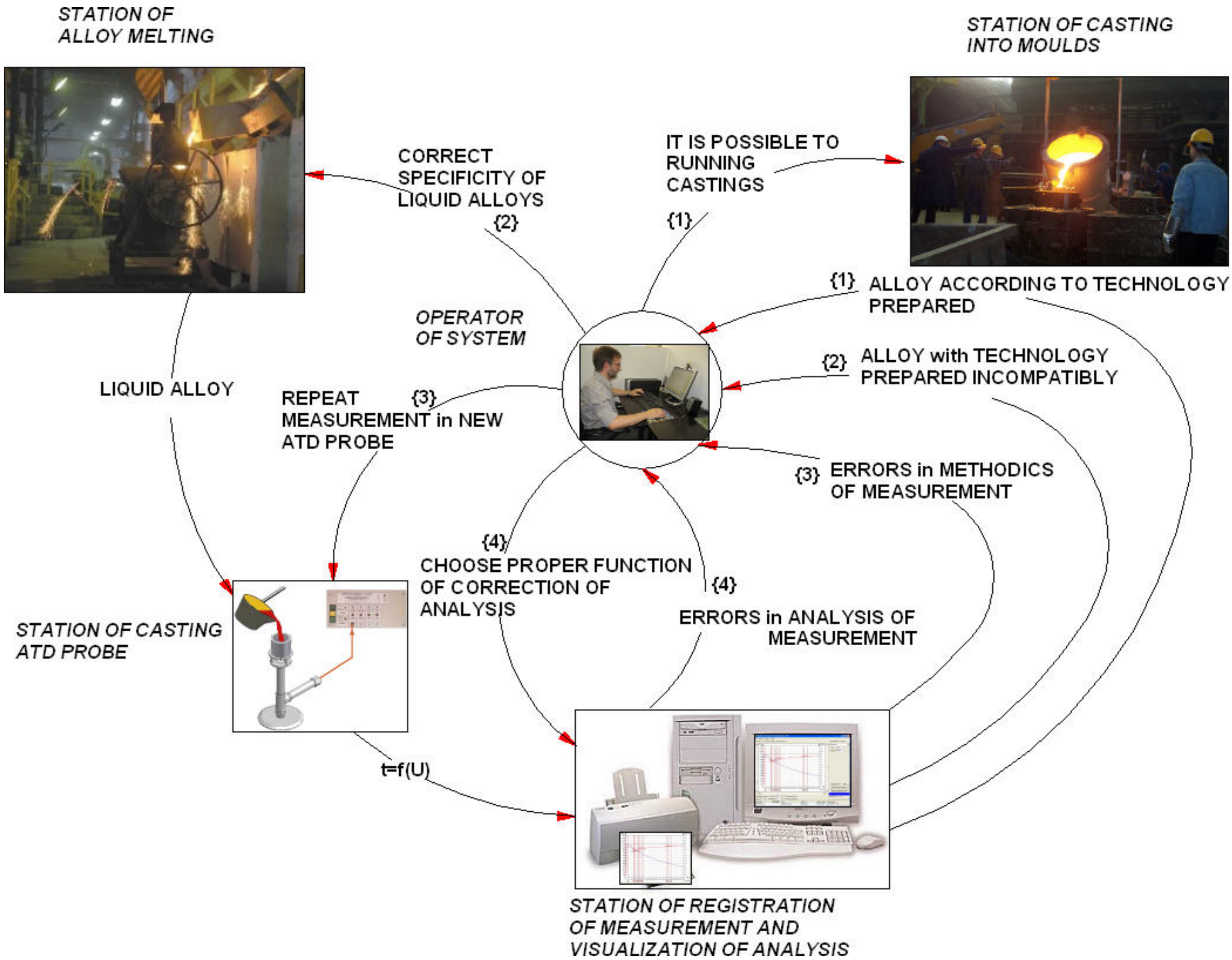


Fig. 4. Schematic representation of alloy control process

From the disclosed data it follows that treatment of cast iron melt and changing its physico-chemical condition is responsible for some important changes in the run of DTA curves. Therefore the control of high-quality cast iron using DTA curves is fully justified.

A schematic representation of the process of molten alloy control is depicted in Figure 4. It shows the measuring procedure and necessary corrections introduced to the melt.

An example of ductile iron control (EN-GJS-500-7 grade) is described below. Basing on the results of examinations of the cast iron chemical composition, mechanical properties $R_{p0,2}$, R_m, A_5 and *HB*, and volume fraction of spheroidal graphite, the relevant relationships between these parameters and the characteristic parameters of DTA curves were derived. The relationships were derived in a way such as to obtain the correlation coefficient of R≥0,90. The results were based on examination of 100 samples from the same number of melts, which ensured high statistical compatibility with the real values.

The statistical relationships are expressed by formulae (1) ÷(10).

(1)

statistical parameters:
d*C* = 0,69%; *C*s = 3,569%; R = 0,95; F = 12,26; W = 5,64

(2)

statistical parameters:
d*Si* = 1,67%; *Si*s = 2,553%; R = 0,93; F = 8,85; W = 4,23

(3)

statistical parameters:

dMn = 4,63%; Mns = 0,514%; R = 0,96; F = 15,07; W = 6,79

(4)

statistical parameters:
dC_E = 1,62%; Mgs = 0,042%; R = 0,92; F = 11,40; W = 4,28

(5)

statistical parameters:
dC_E = 0,65%; C_Es = 4,37%; R = 0,94; F = 21,02; W = 6,27

(6)

statistical parameters:
dR_m = 0,66%; R_ms = 577,4MPa; R = 0,98; F = 28,19; W = 13,08

(7)

statistical parameters:
d$R_{p0,2}$ = 0,99%; $R_{p0,2}$s = 355,0MPa; R = 0,98; F = 22,27; W = 11,01

(8)

statistical parameters:
dA_5 = 1,98%; A_5s = 7,26%; R = 0,93; F = 10,10; W = 4,54

(9)

statistical parameters:
dHB = 1,30%; HBs = 244,5; R = 0,89; F = 7,44; W = 3,15

The volume fraction of spheroidal graphite is:

(10)

statistical parameters:
dN_a09 = 12,42%; N_a09s = 76,9%; R = 0,89; F = 16,98; W = 3,91

Test W is determined by relationship:

(11)

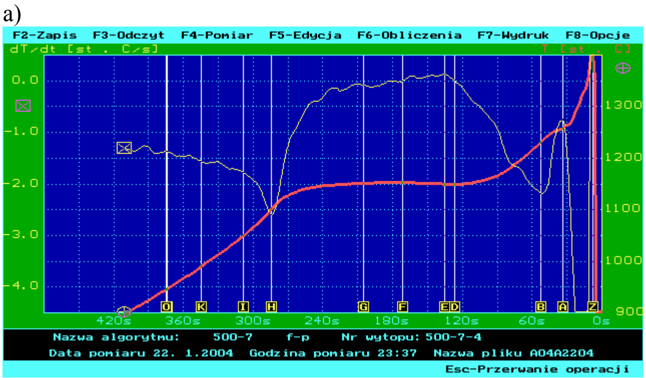
where: – variance of data set, – variance of function.

Minimum admissible value of the reliability test is 2.

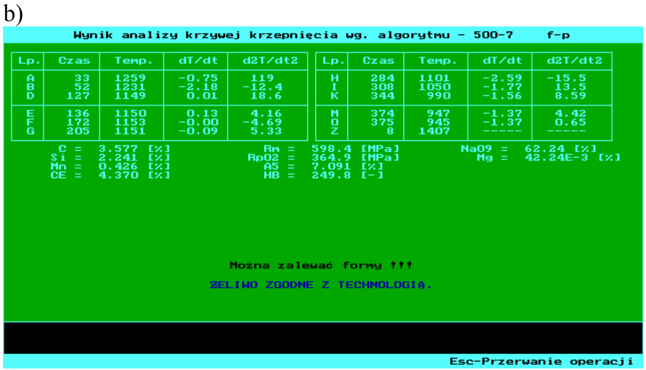
Relationships (1) ÷ (10) served as a basis for construction of algorithms on which the genuine computer program developed by the author for control of ductile iron has been based.

Examples of computer printouts from the program of ductile iron control for melts consistent and inconsistent with the adopted technology are shown in Figures 5 (a, b) and 6 (a, b), respectively.

a)



b)


Wynik analizy krzywej krzepnięcia wg. algorytmu - 500-7 f-p

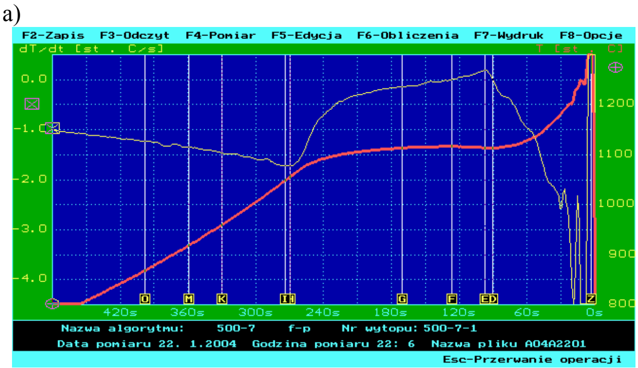
Lp.	Czas	Temp.	dT/dt	d2T/dt2	Lp.	Czas	Temp.	dT/dt	d2T/dt2
A	33	1259	-0.75	119	H	284	1101	-2.59	-15.5
B	52	1231	-2.18	-12.4	I	308	1050	-1.77	13.5
D	127	1149	0.01	18.6	K	344	990	-1.56	8.59
E	136	1150	0.13	4.16	M	374	947	-1.37	4.42
F	172	1153	-0.00	-4.69	O	375	945	-1.37	0.65
G	205	1151	-0.09	5.33	Z	8	1407	-----	-----

C = 3.577 [%] Rm = 598.4 [MPa] Na09 = 62.24 [%]
Si = 2.241 [%] Rp02 = 364.9 [MPa] Mg = 42.24E-3 [%]
Mn = 0.426 [%] A5 = 7.091 [%]
CE = 4.370 [%] HB = 249.8 [-]

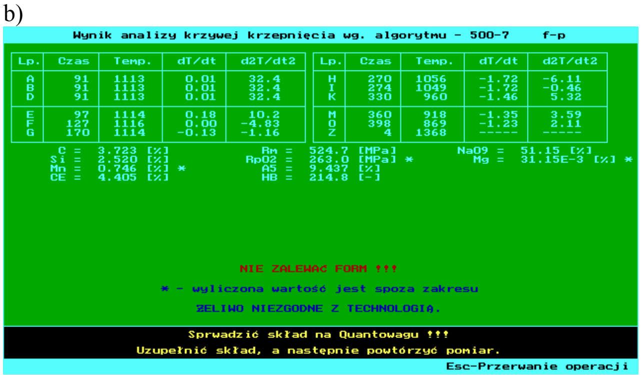
Można zalewać formy !!!
ŻELIWO ZGODNE Z TECHNOLOGIĄ.

Esc-Przerwanie operacji

Fig. 5 (a, b). Examples of printouts from monitor: DTA curves (a) and results of computations (b) for EN-GJS-500-7 cast iron consistent with the adopted technology a)



b)


Wynik analizy krzywej krzepnięcia wg. algorytmu - 500-7 f-p

Lp.	Czas	Temp.	dT/dt	d2T/dt2	Lp.	Czas	Temp.	dT/dt	d2T/dt2
A	91	1113	0.01	32.4	H	270	1056	-1.72	-6.11
B	91	1113	0.01	32.4	I	274	1049	-1.72	-0.46
D	91	1113	0.01	32.4	K	330	960	-1.46	5.32
E	97	1114	0.18	10.2	M	360	918	-1.35	3.59
F	127	1116	0.00	-4.83	O	398	869	-1.23	2.11
G	170	1114	-0.13	-1.16	Z	4	1368	-----	-----

C = 3.723 [%] Rm = 524.7 [MPa] NaO9 = 51.15 [%]
Si = 2.520 [%] RpO2 = 263.0 [MPa] * Mg = 31.15E-3 [%] *
Mn = 0.746 [%] * A5 = 9.437 [%]
CE = 4.405 [%] HB = 214.8 [-]

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ŻELIWO NIEZGODNE Z TECHNOLOGIĄ.

Sprwadzić skład na Quantowagu !!!
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Esc-Przerwanie operacji

Fig. 6 (a, b). Examples of printouts from monitor: DTA curves (a) and results of computations (b) for EN-GJS-500-7 cast iron inconsistent with the adopted technology

The printouts of statistical computations appear on monitor after the recorded curves have been saved and program operator has selected the type of algorithm for computations.

4. Conclusions

From the data presented in the study the followings conclusions have been drawn:

- the metallurgical treatment of cast iron melt, by changing its physico-chemical state, causes certain changes in the run and characteristic features of DTA curves,
- this enables the control of metal alloy melting process,
- the control of alloy melting process and of the alloy properties is done by means of the author's genine computer programs, based on algorithms comprising relevant statistical relationships.

References

[1] S. Pietrowski, Kontrola metodą ATD krystalizacji żeliwa i siluminów,V Międzynarodowa Konferencja Odlewników WSPÓŁPRACA'99

[2] S. Pietrowski, R.W³adysiak, B.Pisarek, Crystallization, structure and properties of silumins with cobalt, chromium, molybdenum and tungsten admixtures, Light Alloys and Composities, PAN Komitet Metalurgii, Zakopane, 1999, s. 77-83

[3] S. Pietrowski, B.Pisarek, R.Władysiak, System komputerowy kontroli i sterowania jakością żeliwa z wykorzystaniem metody ATD, Archiwum Odlewnictwa, vol. 4, PAN – Komisja Odlewnictwa, Katowice, 2002, s. 222-230

[4] S. Pietrowski G. Gumienny, Metodyka przygotowania oceny jakości żeliwa sferoidalnego z zastosowaniem metody ATD, Archiwum Odlewnictwa, vol. 6, PAN – Komisja Odlewnictwa, Katowice, 2002, s. 249-256

[5] S. Pietrowski, Kontrola żeliwa metodą analizy termicznej i derywacyjnej (ATD), Polska Metalurgia w latach 1998-2002, t 2, PAN – Komitet Metalurgii, 2002, s.64-71

[6] S. Pietrowski, G. Gumienny, Ocena jakości żeliwa sferoidalnego EN-GIS-400-15 metodą ATD, Archiwum Odlewnictwa vol. 6, PAN - Komisja Odlewnictwa, Katowice, 2002, s. 257-268

[7] S. Pietrowski, Control of Silumins Crystallization with Thermal and Derivative Analysis Method (TDA), Acta metallurgica Slovaca, vol. 2 2/2002 (2/2), Hutnicka Faculta Technickej Univerzity v Kosiciach, 2002, s. 168-174

[8] S. Pietrowski, B. Pisarek, R. Władysiak, System komputerowy kontroli i sterowania jakością siluminów przeznaczonych na koła samochodowe, Archiwum Odlewnictwa vol. 10, 2003, s. 112-125

[9] S. Pietrowski, G. Gumienny, Ocena jakości żeliwa sferoidalnego ferrytycznego, Archiwum Odlewnictwa, vol. 8, PAN – Komisja Odlewnictwa, Katowice, 2003, s. 256-266

[10] S. Pietrowski, Władysiak R., W. Meksa, Ocena krystalizacji staliwa metodą ATD, Archiwum Odlewnictwa, vol. 8, PAN – Komisja Odlewnictwa, Katowice, 2003, s. 293-300

[11] S. Pietrowski, G. Gumienny, Ocena jakości żeliwa sferoidalnego metodą ATD, IX Międzynarodowa Konferencja Odlewników WSPÓŁPRACA'03,Kraków, s. 107-112

[12] S. Pietrowski, G. Gumienny, Kontrola staliwa GXCrNi72 – 32 metodą ATD, Archiwum Odlewnictwa, vol. 14 Rocznik PAN – Komisja Odlewnictwa, Katowice, 2004, s. 405 – 412

[13] S. Pietrowski, G. Gumienny, Kontrola staliwa GX20Cr56 metodą ATD, Archiwum Odlewnictwa, vol. 14 Rocznik PAN – Komisja Odlewnictwa, Katowice, 2004, s. 315 – 322

[14] S. Pietrowski, G. Gumienny, Meksa M., Woźnicki G., Kontrola staliwa niestopowego metodą ATD, Archiwum Odlewnictwa, vol. 14 Rocznik PAN – Komisja Odlewnictwa, Katowice, 2004, s. 323 – 336

[15] S. Pietrowski, G. Gumienny, B. Pisarek, R. Władysiak, Kontrola produkcji wysokojakościowych stopów odlewniczych metodą ATD, Archiwum Technologii Maszyn i Automatyzacji, vol.24, 2004, s.131-144

[16] S. Pietrowski, G. Gumienny, B. Pisarek, Monitorowanie produkcji i kontrola jakości staliwa za pomocą programu komputerowego, Archiwum Odlewnictwa, vol. 17, Rocznik PAN – Komisja Odlewnictwa, Katowice, 2005, s. 417-432

[17] S. Pietrowski, G. Gumienny, B. Pisarek, R. W³adysiak, Production monitoring and quality control of casting alloys

with TDA method, Worldwide Congress on Materials and Manufacturing Engineering and Technology, 2005, s. 114-116
[18] S. Pietrowski, G. Gumienny, B. Pisarek, R. Władysiak, Monitorowanie produkcji i kontrola jakości stopów odlewniczych za pomocą programów komputerowych, Odlewnictwo – Nauka i Praktyka, Kraków, 2005, nr 3, s. 3-18
[19] B. Pisarek, Influence Cr on Crystallization and Phase Transformations of the Bronze BA1044, Archives of Foundry Engineering, Vol. 7, Issue 3, July-September 2007, pp 129-136
[20] Wdrożenie w WSK GORZYCE S.A. systemu kontroli i sterowania jakością żeliwa austenitycznego na wkładki tłokowe metodą ATD. Projekt Celowy Nr 7T08B 164 99 C/4261, Kierownik Projektu: prof. dr hab. inż. S. Pietrowski,1999-2000
[21] Wdrożenie w "Federal Mogul Gorzyce" S.A. systemu kontroli i sterowania jakością siluminów na felgi samochodowe Projekt Celowy Nr 10T08 080 2001C/5426, Kierownik Projektu: prof. dr hab. inż. S. Pietrowski, 2001-2002
[22] Ocena jakości żeliwa sferoidalnego metodą analizy termicznej i derywacyjnej (ATD). Projekt Badawczy Nr 4 T08B 013 22, Kierownik Projektu: prof. dr hab. inż. S. Pietrowski, 2002-2004