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COMPUTER-AIDED TECHNOLOGY OF MELTING HIGH-QUALITY METAL ALLOYS

WSPOMAGANIE KOMPUTEROWE TECHNOLOGII TOPIENIA WYSOKOJAKOŚCIOWYCH STOPÓW METALI

The paper describes the potentials of computer-aided melting of high-quality metal alloys. This solution enables effective control of alloy quality during melting and before pouring it into the foundry moulds. It is also possible to manufacture castings free from defects caused by alloys of poor quality and effectively control the mechanical properties, e.g. $R_{p0,2}, R_m, HB, A_5$ etc. The genuine computer programs have been and are designed using the principles of derivative thermal analysis (DTA). The algorithms used in these programs are based on statistical relationships which are said to exist between the characteristic parameters of DTA curves and the required properties of castings. The study gives examples of DTA curves plotted for AlSi7Ni5Cu4Mg0,5Cr0,5Fe0,5 silumin, for ductile iron with carbides, and for CuAl10Fe5Ni5-C aluminium bronze. Phase crystallisation responsible for the occurrence of thermal effects on the derivative curve has been discussed. Examples of statistical relationships used for determination of Mg content, R_m value and percent content of graphite characterised by the shape factor close to 1 have been given, and procedures used in control of the alloy melting process have been described. It has been proved that control is an indispensable tool in zero-defect manufacture of castings from high-quality alloys.
Keywords: .....

W pracy przedstawiono możliwości wspomagania komputerowego technologii topienia wysokojakościowych stopów metali. Umożliwia ono kontrolę jakości stopów podczas ich wytapiania, przed odlaniem do form odlewniczych. Zapewnia to otrzymywanie odlewów bez wad spowodowanych niewłaściwą jakością stopów oraz kontrolę ich właściwości mechanicznych, np. $R_{p0,2}, R_m, HB, A_5$ itp. Autorskie programy komputerowe budowane są z wykorzystaniem analizy termicznej i derywacyjnej (ATD). Podstawą budowy algorytmów programów są zależności statystyczne pomiędzy charakterystycznymi wielkościami krzywych ATD, a wymaganymi własnościami odlewów. W pracy przedstawiono przykładowe krzywe ATD dla siluminu AlSi7Ni5Cu4Mg0,5Cr0,5Fe0,5, żeliwa sferoidalnego z węglikami i brązu aluminiowego CuAl10Fe5Ni5-C. Omówiono krystalizację faz powodujących wystąpienie określonych efektów cieplnych na krzywych derywacyjnych. Przedstawiono przykłady zależności statystycznych dla określenia w żeliwie sferoidalnym stężenia Mg, wartości R_m i udziału procentowego grafitu o współczynniku kształtu zbliżonym do 1. Zamieszczono procedury kontroli procesu topienia stopów. Wykazano, że jest ona niezbędna w bezbrakowej produkcji odlewów ze stopów wysokojakościowych.

1. Introduction

The possibility to determine the alloy quality before pouring it into foundry moulds is of primary importance for the successful process of making castings. Knowing the properties of castings even before 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 behaviour. 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 crystallisation curves serve as a starting points for the development of statistical relationships between the chrakteristics of these curves, the alloy chemical composition and the required mechanical properties of cast-

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ings, 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 liquid metal control.

2. Test results

A stand for computer-aided technology of melting high-quality metal alloys is depicted in Figure 1.

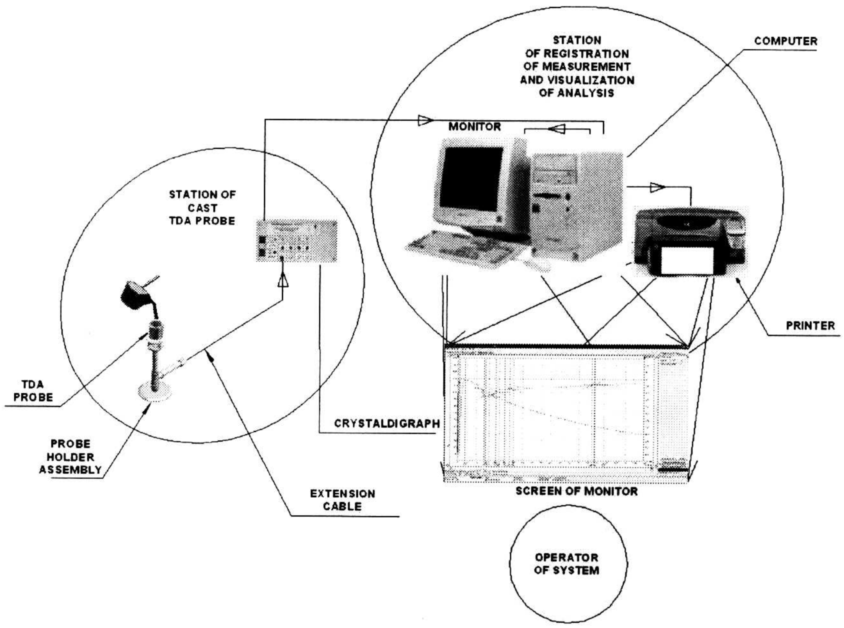
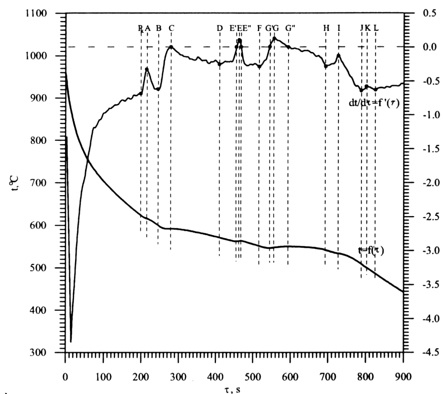


Fig. 1. Test stand for computer-aided quality control of molten alloys

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 temperature time derivative, 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 on a tripod. The tripod holds a DTA probe with quartz pipe, containing on the thermocouple. During the pouring the metal into the probe's mould, the electric signal is transmitted through the thermocouple to the Crystalldigraph, wherefrom it passes to the computer which processing the received informations and plotting two curves: a time derivative curve [t = f(τ)] and a solidification curve [dt/d = f(τ)]. Both curves are displayed on the monitor; they can also be printed by a printer.

For example, Figures 2÷4 show DTA curves plotted for AlSi7Ni5Cu4Mg0,5Cr0,5Fe0,5 silumin (Fig. 2), ductile iron with carbides (Fig. 3), and CuAl10Fe5Ni5-C aluminium bronze with addition of 0,3% Cr (Fig. 4).

a)



b)

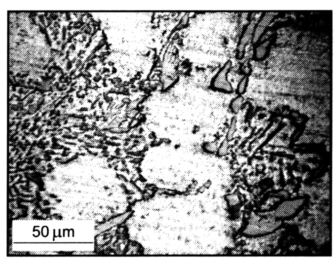


Fig. 2. (a, b). Microstructure (a) and DTA curves (b) for Al-Si7Ni5Cu4Mg0,5Cr0,5Fe0,5 silumin

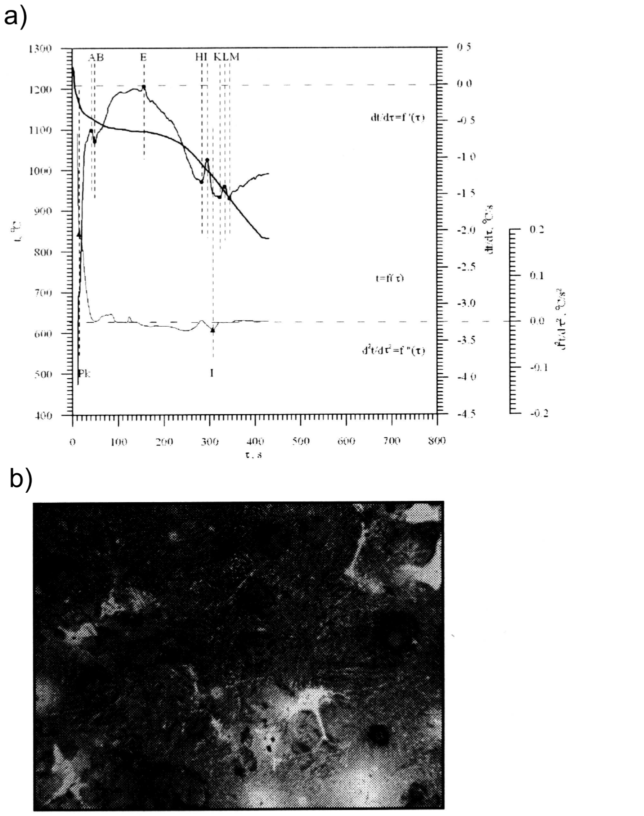


Fig. 3. (a, b). Microstructure (a) and DTA curves (b) for ductile iron with carbides

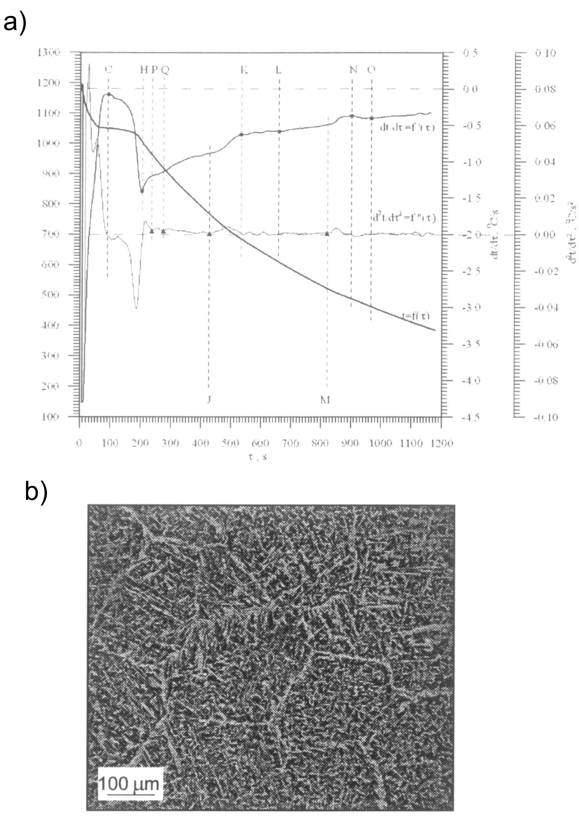


Fig. 4. (a, b). Microstructure (a) and DTA curves (b) for CuAl10Fe5Ni5-C aluminium bronze with addition of 0,3% Cr

The derivative curves of the examined alloys show the thermal effects having their origin in the crystallisation processes of the particular phases and eutectics. For silumin (Fig. 2 a, b) these are the thermal effects related to the crystallisation of: $AlCr_3Si$ phase – P_KAB, phase α – BCD, Al_9Fe_3Si phase – DE′EE″F, – $\alpha+\beta$+$Al_9Fe_3Si_2$ eutectic – FG′G″H,$\alpha+\beta$+Mg_2Si+Al_3Ni eutectic – HIJ, and $\alpha+\beta$+Al_2Cu eutectic – JKK. In ductile iron with carbides, the thermal effects on the derivative curve are induced by the crystallisation of: nodular graphite – AB –,γ+graphite eutectic – BEH, primary carbides – HJK –, secondary carbides – KLM –. In aluminium bronze the thermal effects are induced by the crystallisation of: phase β, – CH – the intermetallic phase rich in iron and chromium – HPQ, partial transformation $\beta \rightarrow \alpha$ – JKL, eutectoid transformation $\beta \rightarrow \alpha+\gamma_2$ – LNO.

Further in the course of action, the characteristic parameters are determined from the DTA curves, i.e. temperature of the beginning and end of phase or eutectic crystallisation and of the maximum thermal effect, the values of the first or second temperature time derivative for these points, and the intensity of cooling rate changes for a determined thermal effect curve section. The DTA curves are plotted for a large number (minimum 50) of the melts of the examined alloys, averaging the values stated previously.

In parallel, on control samples, the following parameters are determined: chemical composition, alloy microstructure and mechanical properties, e.g. $R_{p0,2}, R_m, A_5$ and HB. As a next step, the statistical relationships between the characteristic parameters of DTA curves and the required properties are derived.

For example, for ductile iron grade EN-GJS-500-7, for determination of Mg concentration, the relationship assumes the following form:

$$Mg = -0,112 + 0,000251 \cdot tF - 0,000111 \cdot tK + 0,00050 \cdot KB + \\ +0,00804 \cdot KE - 0,00162 \cdot KH + 0,02103 \cdot KM \tag{1}$$

statistical parameters:
dMg = 1,62%; 4Mg4s = 0,042%; R = 0,92; F = 11,40; W = 4,28

$$R_m = 631,1 + 0,60423 \cdot tB + 1,55442 \cdot tH - 1,8264 \cdot tK + \\ -10,08 \cdot KA + 6,83 \cdot KB - 168,58 \cdot KE + 241,34 \cdot KI + 163,03 \cdot KM \tag{2}$$

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

$$N_a09 = -500,5 + 2,56779 \cdot tD - 2,14254 \cdot tK - 140,05 \cdot KE + \\ +201,00 \cdot KK \qquad (3)$$

statistical parameters:
$dN_a09 = 12{,}42\%$; $N_a09s = 76{,}9\%$; R = 0,89; F = 16,98; W = 3,91
where: Mg – magnesium content in cast iron in %, t_f, t_k etc – temperatures on cooling curves, corresponding to the point F, K etc; N_a – module count in mm^{-2}; KA, KB, KE etc – values of the first temperature time derivatives corresponding to the point A, B, E etc.

Using the computed statistical relationships, an algorithm is constructed, and next a computer-aided program for quality control of alloy melt is developed.

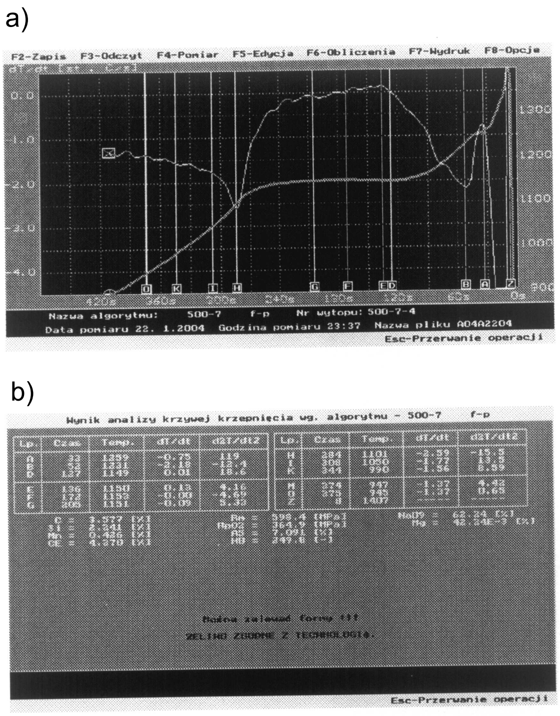


Fig. 5. (a, b). Examples of printouts from monitor: DTA curves (a) and results of computations (b) for EN-GJS-500-7 cast iron consistent with the applied technology

The procedure of alloy control is consistent with the description given below. Liquid alloy from a melting installation is poured into a DTA probe. From the voltage signal transmitted to the Crystalldigraph and from Crystalldigraph to the computer and next to the monitor, two curves are plotted and displayed on the monitor. These are the curves t = f(τ) and dt/dτ = f(τ). The computer determines and calculates the characteristic values of these curves, to compute next the required quantities. Examples of DTA curves printed out from monitor (a) and results of calculations (b) for EN-GJS-500-7 cast iron consistent with the adopted technology are shown in Figure 5 (a, b).

The printouts from monitor for cast iron inconsistent with the adopted technology are shown in Figure 6 (a, b).

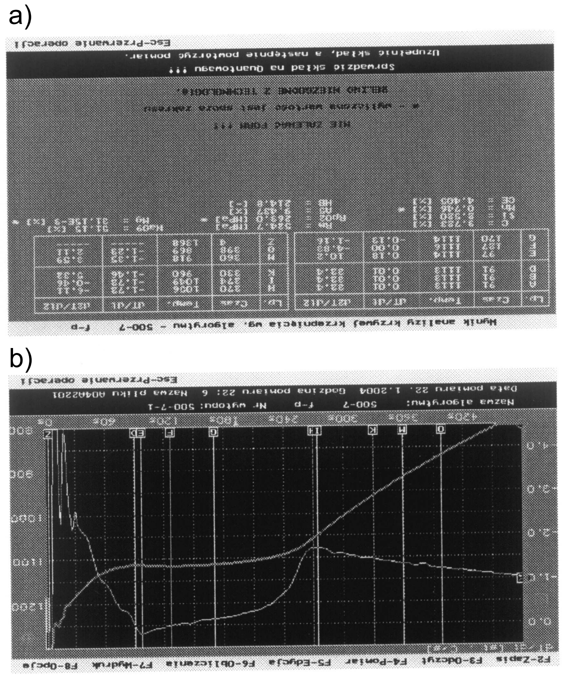


Fig. 6. (a, b). Examples of printouts from monitor: DTA curves (a) and results of computations (b) for EN-GJS-500-7 cast iron inconsistent with the applied technology

Schematic representation of alloy control process is shown in Figure 7.

Depending on the results displayed on monitor screen, the operator of the system takes the decision: either currying out correction in the metal composition or allowing the metal to be poured into moulds.

The aforementioned example of computer-aided process of metal alloys melting has been successfully implemented in the industry for: aluminium alloys (production of pistons operating in I.C. engines and wheels of vehicles), ductile iron (also with carbides), and cast steel, both unalloyed and alloyed grades.

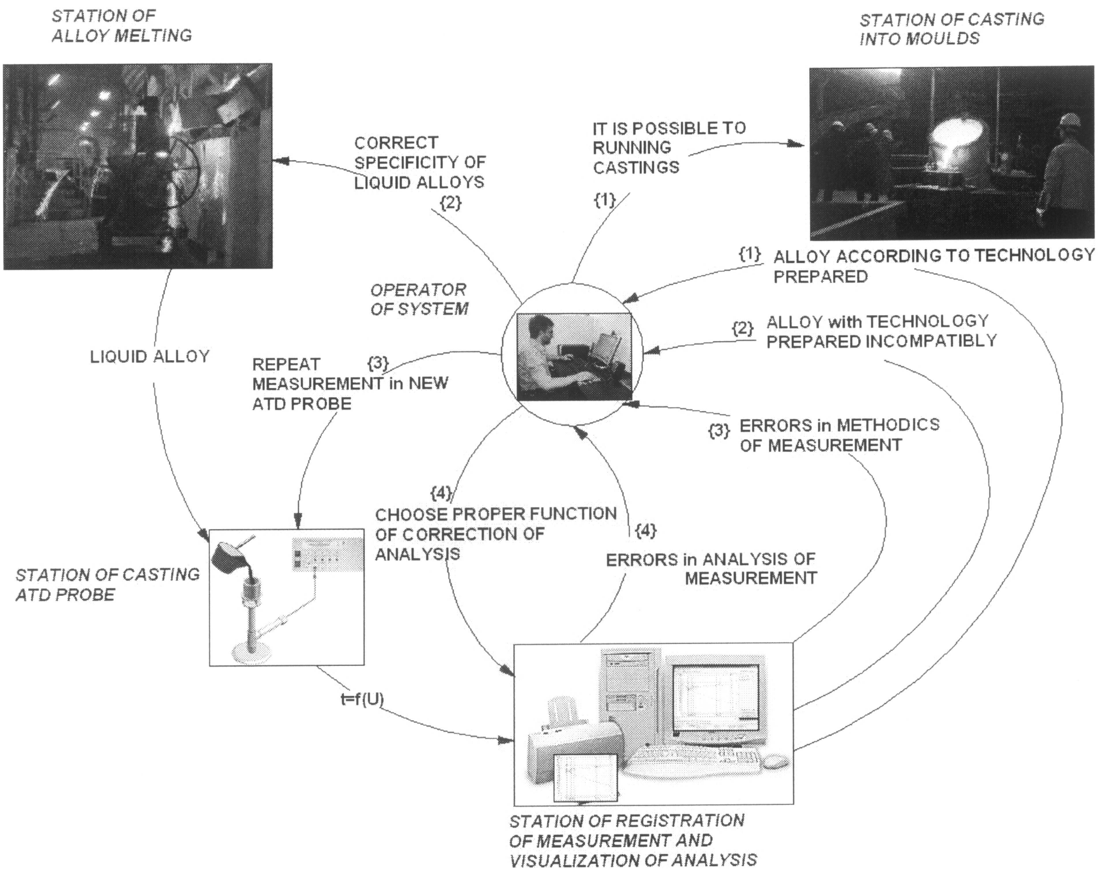


Fig. 7. Schematic representation of alloy control process

3. Conclusions

From the data presented in this study the following conclusions have been drawn:

– DTA curves describe physico-chemical properties of alloys,
– there are statistical relationships with correlation coefficient R>0,9, existing between the typical parameters of DTA curves and mechanical properties of alloys,
– the statistical relationships may be bases of the algorithms prepared for computer programs,
– the genuine computer programs for control and monitoring of alloy melting technology ensure effective elimination of casting rejects caused by microstructure defects and improve the related mechanical properties.

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