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Quality Prediction of Spheroidal Graphite Cast Iron for Machine Tool Parts

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Today, considerable attention is paid to the production of solid castings (approx. 2000 kg) from cast iron with spheroidal graphite. The metallurgical preparation of large quantities of melt is very difficult. This difficulty is related not only to the melting and preparation of large quantities of melt, but above all to its metallurgical treatment - inoculation and modification. Melt modification ensures the production of cast iron with spheroidal graphite. Material castings, such as machine tool components, cannot be destroyed to determine the quality of the cast iron produced. Therefore, this paper outlines a methodology to proceed in determining the quality of manufactured castings. It is possible to observe the chemical composition of cast iron, thermal analysis of cast iron using liquidus temperature value, subcooling temperature, eutectic recalescence, primary solidification recalescence, eutectic solidification time. Furthermore, to observe the mechanical values of cast iron (yield strength, ultimate strength and ductility) on fabricated bars of overmolded Y blocks or to observe the microstructure of cast iron on microscope.

Keywords: Spheroidal graphite cast iron, Rotary drum furnace, Inoculation, Modification, Thermal analysis

1 Introduction

More than 60 years have passed since the beginning of industrial production of cast iron with spheroidal graphite. Globular graphite cast iron is one of the important structural materials, which shows very good mechanical properties already in the as-cast condition. Today, this cast iron finds application in various areas of industrial production, such as the mechanical engineering and automotive industries. Historically, two independent sites were involved in the development of its production in the 1940s. One was the British Cast Iron Research Association (BCIRA) research laboratory, where researchers Henton Morrough and Williams conducted experiments on the effect of cast iron with flake graphite in the presence of cerium [1]. The second site was the American International Nickel Co. (INCO), here a team of workers led by Keith Millis looked at replacing precious nickel in the production of wear-resistant cast iron with other metals, for which metallic magnesium was used as reported in [2]. This developed a second method of modifying the shape of graphite using metallic magnesium. Soon licenses were sold and the production of this type of cast iron began to be tested in various industrialized countries, including our own. The publication of the British patent [3] essentially mentions a method of producing a grade of cast iron which, according to our present knowledge, gives a prerequisite for the production of cast iron with spherical graphite. The origin of spheroidal graphite in cast iron was published in 1935 by NIPPER [4]. As reported by some foreign sources, research to obtain spherical graphite in cast iron was carried out by [6] between 1936 and 1938. In 1938, he also submitted the production of cast iron with spheroidal graphite for patenting. By publishing the result of his work ten years later, only in 1948, therefore, the invention of the production of cast iron with spheroidal graphite in Europe is attributed to Morrough and Williams, who published the production of cast iron with spheroidal graphite as early as 1947 [1]and modified the melt with cerium in their research on cast iron with spheroidal graphite. A number of monographs have been published worldwide on the production of cast iron with spheroidal graphite, such as [6,7] and [8]. The theory of solidification and the formation of graphite in cast iron with spheroidal graphite are currently known works mainly [9,10,11]. Researcher [12] has extensively studied the production of cast iron with spheroidal graphite. In the Czech Republic, the first smelting of cast iron with spheroidal graphite was carried out in 1949 and 1950 in several Czech foundries by researcher [13]. Further intensive development gradually took place after 1966, when the patents for the production of this type of cast iron expired. There were many technical problems associated with the production of this type of cast iron. These problems were solved in various scientific departments, universities and production plants. Nowadays, the problem of production of cast iron with spheroidal graphite has been dealt with by many researchers, who has studied the theoretical laws, but also the practical production of cast iron with spheroidal graphite [14,15,16,17].

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The production method was focused on the preparation of cast iron melt with ball graphite for the production of very heavy castings weighing approximately 2000 to 5000 kg. This casting is a machine tool spindle - WHR13, which is made from EN-GJS-600-3 nodular graphite cast iron. Figure 1 shows a schematic of the spindle and boring machine, where the spindle is an important structural part.

The spindles produced according to the proposed technology were initially without defects, but later the production of these castings already recorded a high incidence of non-repairable defects such as stagnation and dilution. Fig. 2 shows a diagram of the spindle workpiece with the important functional areas marked and a diagram of the casting in the foundry mould.

Therefore, the first design of the position of the casting in the mould considered placing these surfaces at the bottom of the mould to ensure their quality. This option proved to be very challenging for the actual insertion of the cores into the mould. There would be a large mass of moulding compound in the top of the mould into which additional cores would have to be secured (by tying or gluing), which would be problematic just by rotating the top frame. Fig. 2 shows an example of a suitable casting arrangement in a foundry mould. In addition to the choice of the position of the casting in the foundry mould, the parting plane, the positioning of the sprues, the coolers and the sprue system were chosen. Basically, the optimization of the casting production was carried out. For this purpose, a simulation program for melt filling and solidification of the casting in the mould, QuikCAST, was used.

On the basis of the simulation calculation with the application of pourers and coolers, the foundry mould was designed, see Fig. 3.

Fig. 1 *Cast iron spindle with globular graphite and diagram of horizontal boring machine WHR 13 with spindle marking*

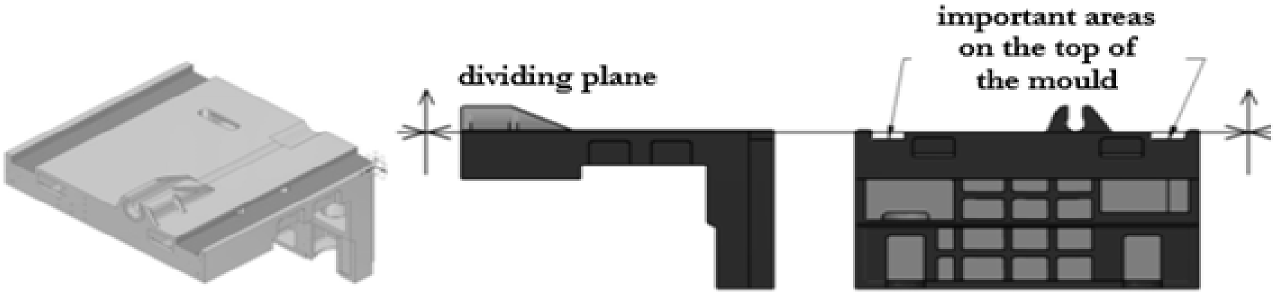

Fig. 2 *Spindle WHR 13 (Q) and used casting position in the foundry mould*

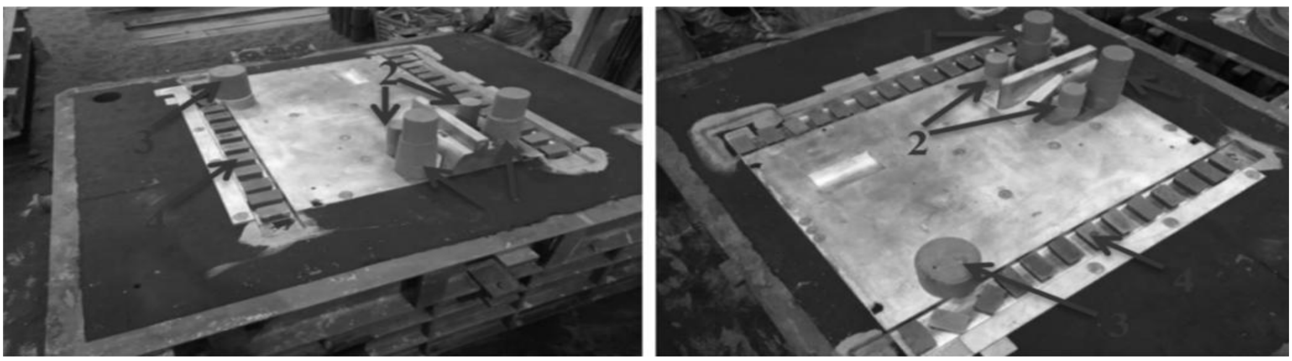

Fig. 3 *Foundry mould with a model of a moulded spindle after modified technology based on numerical simulation*

Where:
1…Exothermic heat exchanger EK-70-100-W-SF-I;
2…Exothermic heat exchanger F13-15-34 +Z0-13+ EK100-130 W; 100-W-SF-I;
3…Exothermic heat exchanger EKW 160 W;
4…Cooler No. 3.

2 Metallurgical preparation of the melt

Two drum rotary furnaces with an oxy-gas burner were used simultaneously for the metallurgical preparation of a large amount of melt of cast iron, see Figure 4. One furnace has a capacity of 5 t output (5t/2h), the other has a capacity of 12 t (12t/2h). The standard melt preparation in both furnaces takes 2 to 2.5 h.

The rotary drum furnace is lined with an acid lining, which is heavily stressed not only by high temperatures but also by mechanical wear, especially during the loading of the charge and when the melting and „rolling“ of the furnace contents begins. The lifetime of the lining depends on many factors, e.g. the quality of its packing during the baking process or the number of melts per day, etc. The standard number of melts per campaign (number of melts per new lining) is around 300. The whole melting process and the metallurgy of the melt is greatly influenced by the combustion of the flue gases in the furnace atmosphere, which are in direct contact with the metal. During melting in a rotary drum furnace, the loss (combustion) of basic elements is most often 10 - 15 % C, 15 - 20 % Si, 25 - 32 % Mn. It is quite complicated to keep the required carbon content in the furnace, especially when several ladleful are carried out and the cast iron has to stay for a longer time in the furnace at the required temperature. The charge was made up of pig iron (30-50 %), returnable material (reject castings, gating systems, risers), steel scrap and slagging additives (0,5-1 %). The carbon content is obtained by the smelter mainly from pig iron, but it can be adjusted using carburizers. Ferroalloys can be added to the melt or can also be part of the charge. The length of a single smelting process is between 90 and 180 minutes, depending on the ladleful temperature and the size of the furnace. The maximum temperature in a rotary drum furnace can reach up to 1550 °C, but this is already very undesirable for the life of the lining, so it is not recommended to exceed 1480 °C.

The preparation of the melt for nodular cast iron in both furnaces is then carried out analogically separately up to a temperature of 1420 °C, after reaching this temperature the furnace is poured, during which the first inoculation of the melt directly into the metal stream is carried out using 0.2 wt.% of the VP216 in powder form. This inoculated melt flows into a preheated casting ladle with a required volume of 4 tonnes. Between 2 and 3 tonnes of melt are poured into this pan. After the first inoculation into the metal stream, the temperature of the melt is measured and then the melt is transferred in the ladle to the workstation where the melt modification takes place. At this workstation, using a Progelta metallurgical station, the modification of the melt is carried out with a filled profile. Secondary inoculation of the melt is also carried out. The prepared cast iron melt with spheroidal graphite has a eutectic composition.

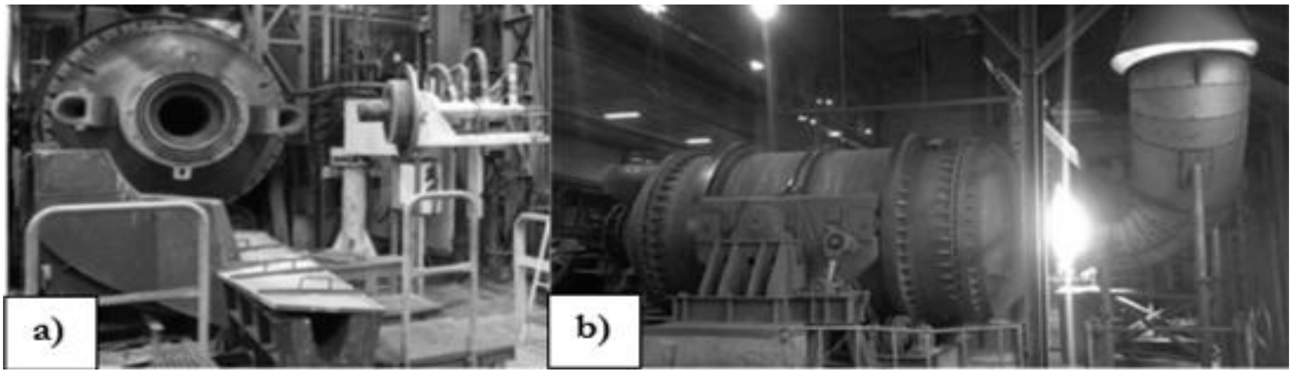

Fig. 4 *Rotary drum furnaces; a) 5 t rotary drum furnace; b) 12 t rotary drum furnace*

The chemical composition of the cast iron melts was checked on a Tasman Q4 spark spectrometer. A small „penny“ shaped sample is cast from each melt into a copper cocktail and the chemical composition is then checked. Table 1 shows the chemical composition of the melt from each ladle. The chemical composition of each ladle is in accordance with the Internal Manufacturer's Code for GJS 600-3.

Tab. 1 *Chemical composition spheroidal graphoite iron GJS 600-3*

Chemical composition spheroidal graphite iron EN GJS 600 - 3[wt. %]						
Element	Basic melt from furnace	Ladle 1	Ladle 2	Ladle 3	Ladle 4	Ladle 5
Carbon	3.505	3.547	3.625	3.562	3.573	3.701
Manganese	0.480	0.500	0.504	0:510	0.515	0.522
Silica	2.027	2.490	2.445	2.511	2.532	0.056
Phosphorus	0.052	0.058	0.057	0.057	0.056	0.056
Sulphur	0.025	0.014	0.012	0.013	0.013	0.014
Copper	0.155	0.587	0.511	0.161	0.165	0.318
Magnesium	0.001	0.055	0.064	0.049	0.051	0.052
CE	4.18	4.38	4.44	4.40	4.45	4.56

3 Evaluation of the quality of the melt produced

3.1 Thermal analysis of the melt

The evaluation of the quality of produced material castings, such as this spindle (approx. weight 2000 kg) is very difficult and would require the destruction of these castings. Therefore, a metallurgical evaluation of the quality of the liquid metal is performed for the production of cast iron with spheroidal graphite. In cooperation with Technical Service Kuehn GmbH and DETYCON Solutions s.r.o., the quality of the liquid metal was measured by AccuVo thermal analysis and then evaluated using Apromace software. The purpose of this measurement was to determine whether the amount and type of the used opacifier and modifier has the desired effect in the production of cast iron with spheroidal graphite according to EN GJS 600-3. Fig. 5 shows an example of the cups used for the thermal analysis of cast iron.

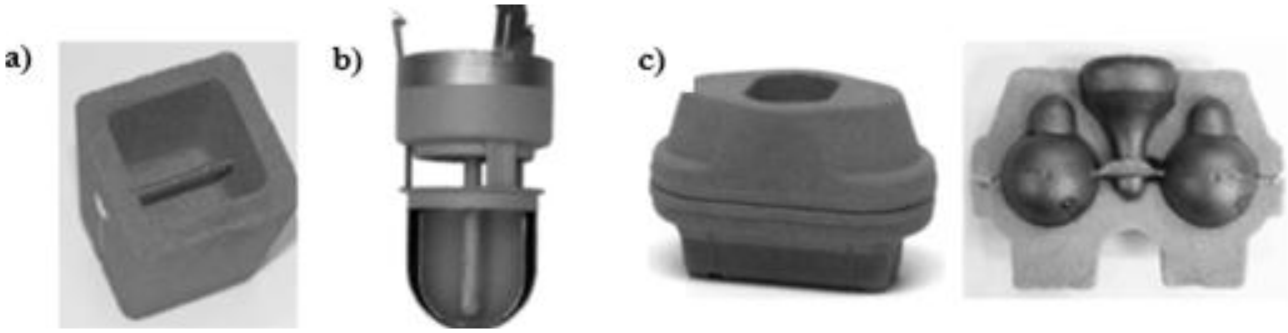

Fig. 5 *Cups for thermal analysis; a) Classic open cup with thermocouple; b)Steel cup with two thermocouples in a protective tube; c)AccuVo dual-chamber cup*

In the thermal analysis, the melt was scooped from the metal stream with a ceramic ladle during furnace blasting prior to primary operational inoculation using 0.2 wt% VP216 powdered inoculant. This melt, or „pure“ base metal, was then poured into two Open Cup cups, one of which had a tellurium coating. This procedure has long been established in thermal analysis (TA) measurements, as the solidification curve can be used to determine the liquidus temperature value, including any recalescence, quite reliably under certain conditions. If the chemical composition is approximately eutectic, the reproducibility of the measurement with a standard Open Cup ensuring solidification according to an equilibrium stable Fe-C diagram is not guaranteed. In addition, the Open Cup method is subject to measurement errors if the amount of melt in the cup is not uniform. When performing the experiment in the foundry, the liquid temperature was deliberately measured using both Open Cups and the AccuVo sensor. The measured liquid temperature (Tliq) values are shown in Table 2. From these values, their variability is evident. The inaccuracy of the Tliq temperature measurement is evident when using Open Cups.

Tab. 2 *Comparison of liquid temperature values according to different thermal analysis methods*

Number of the ladle	Temperature of liquid T_{liq} [°C]		
	Open Cup + Te	Open Cub without Te	AccuVo
1	1148.9	1143.3	1147.7
2	1144.7	measuring error	1138.8
3	1146.2	1142.3	1144.7
4	1131.4	1141.0	1138.1
5	1115.2	1168.1	1159.0

After the casting of these two Open Cup crucibles (at the first site - melt without metallurgical treatment), one more AccuVo crucible was cast, where one of the chambers was "clean" and the other contained 0.04 wt.% of VP216 inoculant, i.e. the same type as used as standard. However, in batch dosing into the metal stream, 0.2 wt. % of VP216 vaccine is used in the foundry. The target of the melt sampling at the first site was to obtain solidification records from the base "clean" metal and from the melt inoculated with 0.04 wt. % of VP216 inoculant. This procedure can be used to assess how the melt obtained directly from the melting furnace (the base melt in the melting furnace) responds to very low doses of vaccine. Also, if there is not much difference between the curves that characterise the eutectic transformation, a very good condition of the melt and a sufficient number of suitable crystallisation nuclei can be considered. Subsequently, the melt was operationally primary vaccinated using a standard procedure (0.2 wt% of VP216 inoculant was added to the melt stream). Prior to modification and secondary inoculation, another melt sample was collected (checking the melt condition after primary inoculation with 0.2 wt% VP216 inoculant). It was possible to compare the condition of the melt inoculated in the AccuVo cup with 0.04 wt.% and with 0.2 wt.% inoculated with VP216 during serial production. Subsequently, modification with Progelta LSK 13412BS filled profile was performed. The modified melt was cast into an AccuVo cup, with a chamber containing no inoculum to examine the condition of the modified melt and chambers with a 0.04 wt% Inuculine or 0.04% SMW605 inoculation to view the melt response to these inoculants prior to serial secondary inoculation. After the end of the 3rd collection, secondary inoculation with Progelta WIN 13A was performed under serial conditions. Again, a sample was taken to determine the melt condition. The aim of these sampling was to determine the efficacy of the different types of secondary inoculations. After the slag was withdrawn, the moulds were cast. From the remaining melt in the casting ladle, a final sample was taken in an AccuVo crucible containing 0.04 wt% Inoculin inoculant in one chamber and 0.04 wt% SMW605 inoculant in the other chamber. The purpose of this last sampling was to determine the condition of the melt at the end of the casting and whether the metal would still respond in any way to a third inoculation in a row.

From the thermal analysis experiments performed on the cast melt, temperature-time relationships or solidification curves were obtained, e.g. see Fig. 6.

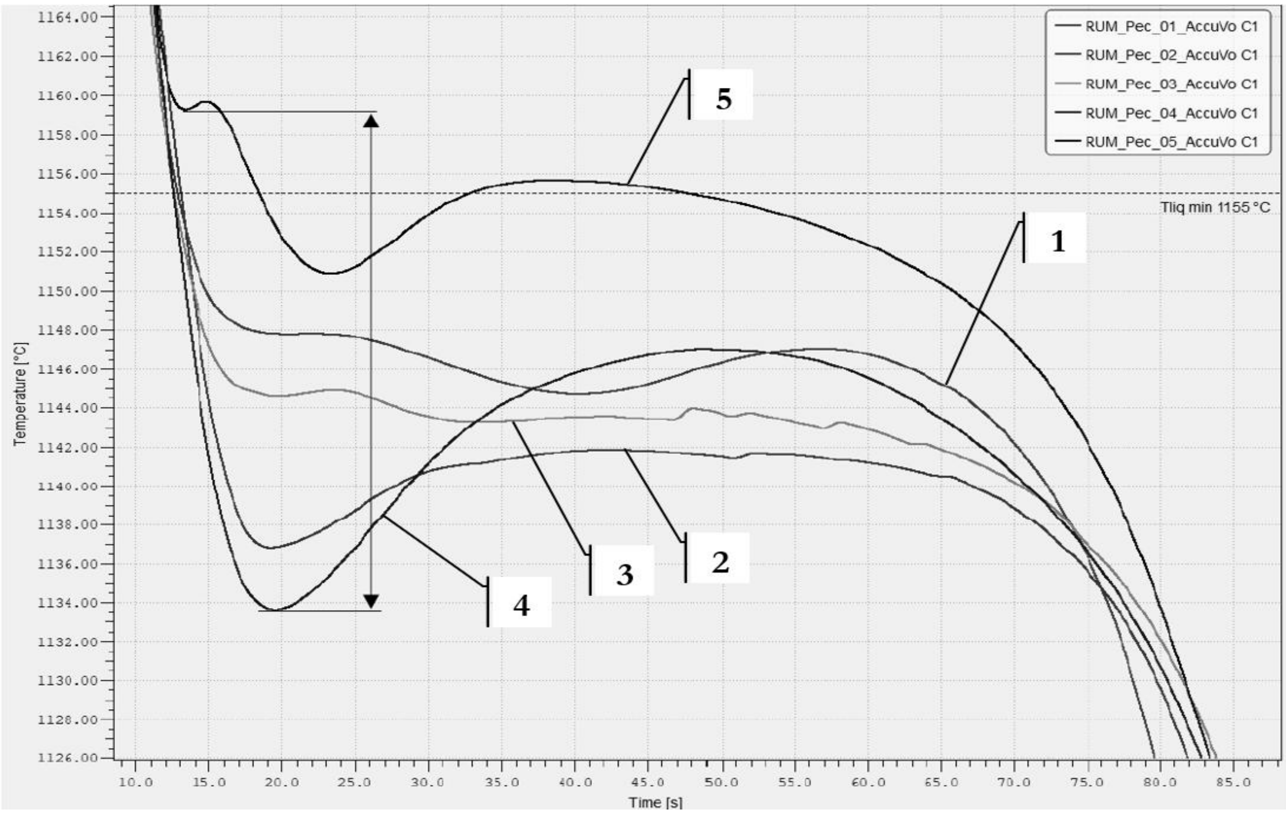

Fig. 6 Temperature-time and solidification curves of lithane melt with ball graphite produced in a rotary gas furnace the number corresponds to the respective ladle

Where:
1…Ladle 1;
2…Ladle 2;
3…Ladle 3;
4…Ladle 4;
5…Ladle 5.

3.2 Evaluation of the solidification character and T_{liq} of the base melt from a rotary drum furnace

Fig. 6 shows five records of solidification curves (from five ladles) from an Ac-cuVo cup, all of these samples were taken with a ceramic ladle from the metal stream prior to the primary batch inoculation with 0.2 wt% VP216 inoculant. From the individual solidification curves, the large variation in liquidus temperatures for each sample can be seen, see Table 2. This is an illustration of how problematic it is to achieve stable solidification with eutectic melt compositions. The analysis of 5 samples shows that the temperature range at which the melt starts to solidify is over 25 °C (1133.6 - 1159.2 °C), see the black line in Fig. 6. Since the charge, according to the settings in the foundry, had a eutectic chemical composition, the unmodified, uninoculated metal should solidify eutectically, but as can be seen from Fig. 6, the solidification behaviour of samples taken from different ladles is very different. From one furnace, the melt was poured into 5 ladles, and as can be seen, ladle 1 (red curve) solidified sub-eutectically, ladle 2 (purple curve) eutectically, ladle 3 (green curve) sub-eutectically, ladle 4 (blue curve) eutectically, ladle 5 (black curve) super-eutectically. However, the solidification processes marked as sub-eutectic by the green and red curves can be described as "two-stage near-eutectic solidification". The eutectic composition of the charge alone does not guarantee that the melt will solidify eutectically without the solidification inclining to super- or sub-eutectic solidification. This phenomenon occurs with melts prepared especially in rotary furnaces, where the homogeneity of the chemical composition of the melt removed from the furnace is not always assured for each ladleful. In the furnace, the carbon in the melt remains at the surface and therefore its highest content is always in the last ladle, see sample taken at the last ladleful - ladle 5. Controlling the chemical composition of individual strippings is problematic, but accurate and especially rapid thermal analysis gives the opportunity to address the melt condition either by subsequent carbonisation or dilution, or under certain restrictive conditions by targeted dosing of a suitable modifier and inoculant.

3.3 Evaluation of the effect of primary inoculation

The evaluation of individual measurements was performed for all 5 pans, but to present the influence of different amounts of inoculant on the eutectic response, samples from ladle 4 were chosen. Fig. 7 therefore shows the solidification curves of the base metal from the rotary furnace before primary inoculation (red curve), the standard primary inoculated metal on the spout into the metal stream with 0.2 wt% VP216 inoculant (blue curve) and metal inoculated in an AccuVo cup containing 0.04 wt.% VP216 inoculant (green curve). As can be seen from the progression of the blue and green curves, the 5-fold inoculation at the spout (0.2% VP216 compared to 0.04%), which is done as standard in the foundry, does not have much effect. Nor are there large differences between the red and blue curve waveforms. T_{eutLo} and T_{eutUp} temperatures increased by about 5 °C for the primary inoculated metal (0.2 wt.% VP216 - blue curve) compared to the uninoculated state (red curve). Moreover, the difference between the eutectic recalescence for the uninoculated metal (red curve T_{eutUp} - T_{eutLo} = 13.5 °C) and the primary inoculated metal (blue curve TeutUp - TeutLo = 14 °C) is only 0.5 °C. However, there is a similarly small difference (1.5 s) in the eutectic solidification time, which was 30 s for the uninoculated metal (red curve) and 28.5 s for the primary inoculated metal (blue curve). The solidification curves are very similar, suggesting that primary vaccination appears to be completely unnecessary. It would certainly be sufficient to inoculate 0.04 wt.% VP216 (green curve) and even this appears to be unjustified.

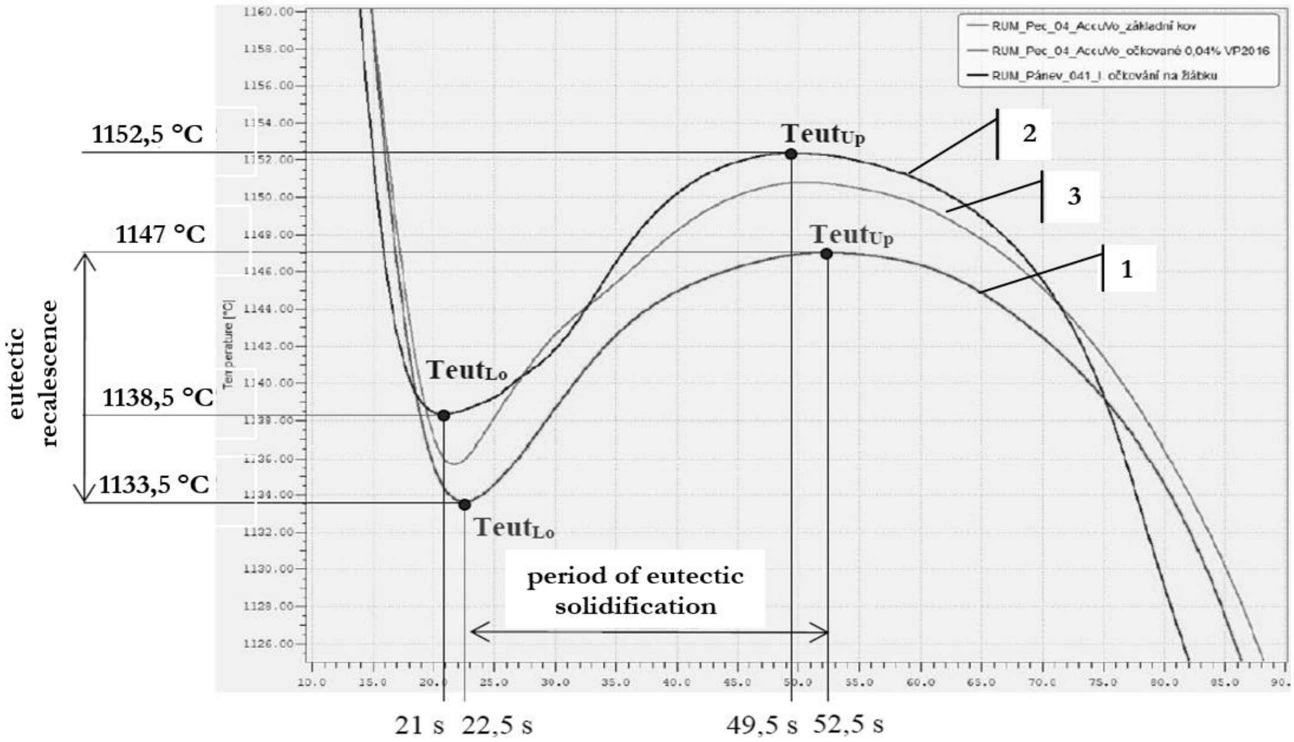

***Fig. 7** Temperature-time curves with significant eutectic solidification area of cast iron with spheroidal graphite melt, influence of eutectic solidification by VP216, ladle 4*

Where:
1…Base melt before primary inoculated;
2…Primary inoculated on 0.2 wt % VP216;
3…Melt inoculated in AccuVo 0.04 wt % VP216.

4 Evaluation of melt condition after primary inoculation and modification

Again, melt samples from ladle 4 were used to show the results of the thermal analysis to see how the modification affects the melt (liquid metal). Fig. 8 then shows the individual solidification curves showing how the eutectic temperature and solidification character changes after modification of the liquid metal in the production of EN GJS 600-3 cast iron. The red curve here again represents the base metal before primary inoculation and the blue curve characterises the metal after primary inoculation. The purple curve represents the state of the liquid metal after modification. Magnesium as an anti-graphitization element changes the whole character of the eutectic solidification, which changes to a 2 degree solidification (see T_{liq} and T_{eut} display) in Fig. 8, where the solidification of austenite is separated from that of graphite, reducing the solidification temperature by more than 4 °C and the recalescence is substantially reduced.

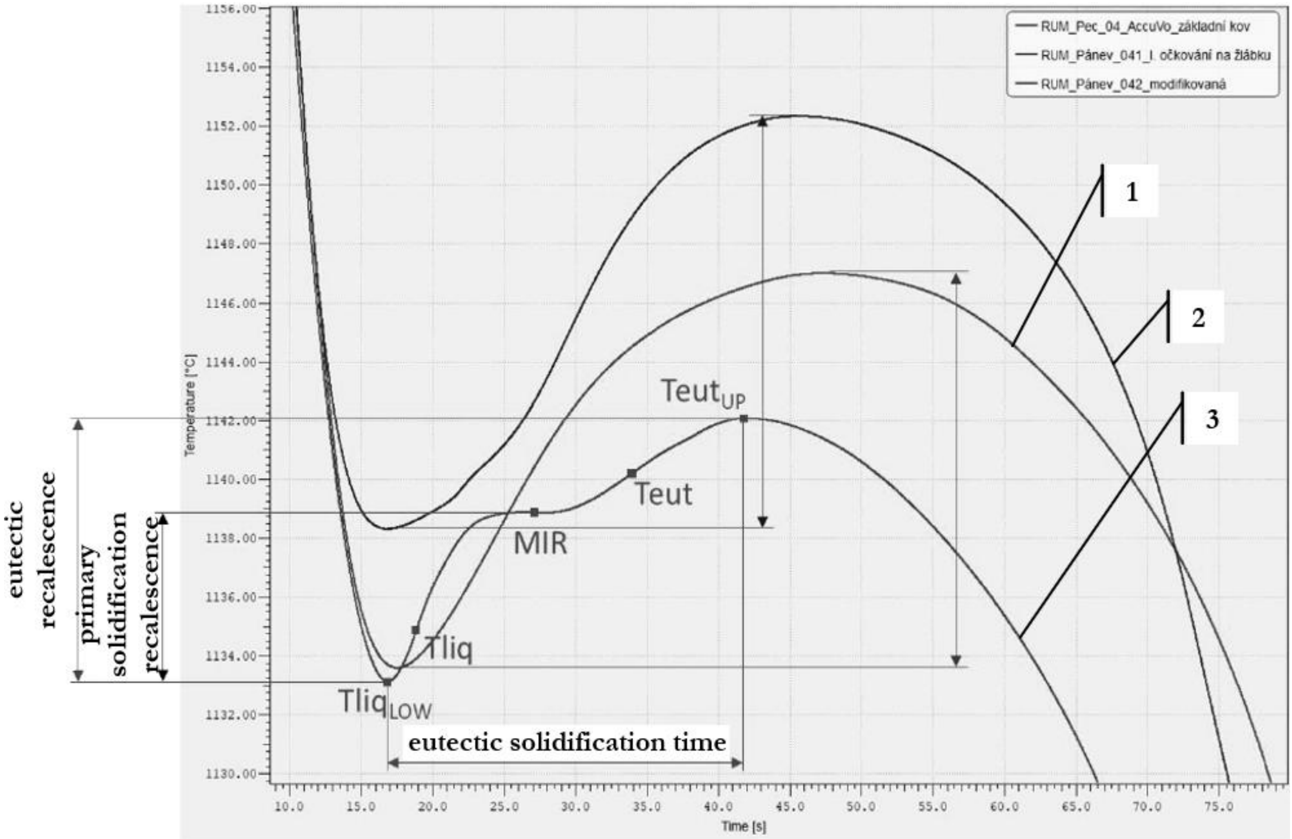

Fig. 8 *Temperature - time dependence, display of Teut eutectic temperature before and after modification, ladle no. 4*

Where:

1…Base melt prior to inoculation;

2…Promotional inoculation on the spout;

3…Melt after primary inoculation and modification.

5 Mechanical values and microstructure of cast iron

Based on the melts, two tensile test bodies (sample 1 and sample 2) were fabricated. These samples were cast from a standard prepared melt (ladle no. 4). A Y-block of type 2 was cast, from which 2 test rods of 10 mm diameter were produced for tensile testing and 1 sample for metallography. The static tensile test was carried out on a TIRA test 2300 tear tester in accordance with EN ISO 6892-1. The measured mechanical properties of these samples are given in Table 3.

Tab. 3 shows that the mechanical values of the cast iron obtained in the static tensile test correspond to the values prescribed.

Furthermore, a metallographic evaluation of the structure of the sample from ladle no. 4 after inoculation and melt modification was carried out on a light microscope. The sample for metallographic observation was prepared by conventional metallographic procedure and 3% Nital was used to highlight the structure. The microstructure obtained can be seen in the Fig. 9.

From Fig. 9 it is clear that this is a microstructure of cast iron with spheroidal graphite. The graphite spheres are excluded in a regular grain shape. The granular graphite corresponds to size classes 6 (from 30 to 60 μm) and 7 (from 15 to 30 μm). The cast iron is perlitic-ferritic, with a ferrite content of up to 30 % and a perlite content of up to 70 %.

***Tab. 3** Determined mechanical values of spheroidal graphite cast iron*

Number of the ladle	Mechanical properties		
	$Rp_{0.2}$ [MPa]	Rm [MPa]	A_{50} [%]
1	391.5	568.8	6.90
2	395.1	575.6	7.17
Everage values	393.3	572.2	7.04
Standard deviation [MPa]	1.80	3.40	0.14
Coefficient of variation [1]	$4.58\cdot10^{-3}$	$5.94\cdot10^{-3}$	$1.99\cdot10^{-2}$

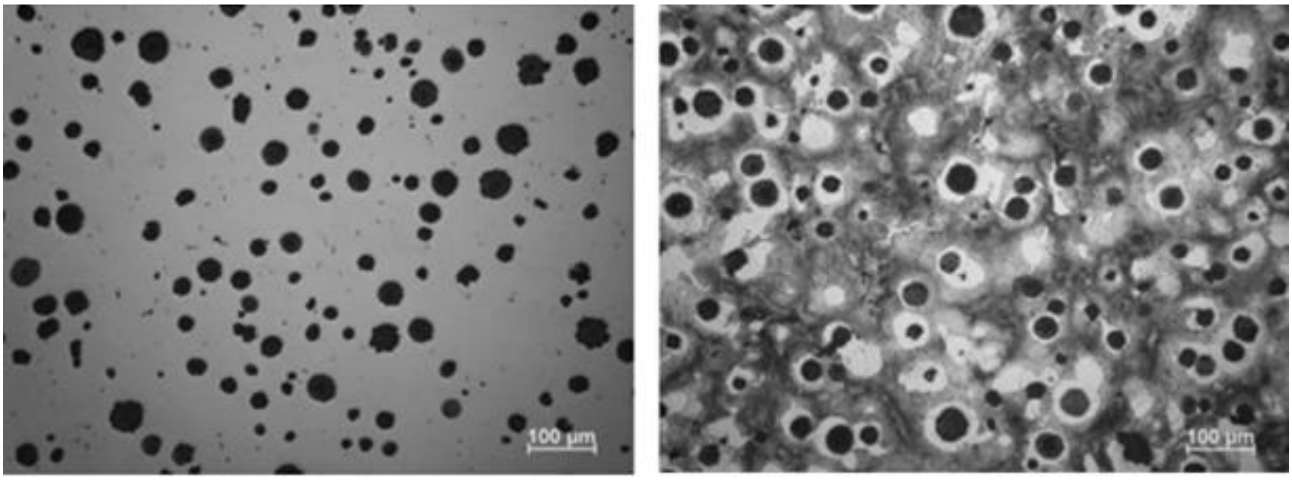

***Fig. 9** Microstructure of cast iron with spheroidal graphite in the unetched state (left); in the etched state with Nital 3% (right), ladle no. 4*

6 Results discussion

This article gives the first information on the possibilities of melt preparation for the production of very massive castings. From cast iron with globular graphite. The results obtained for this cast iron are closely related to the facts subsequently presented.

The production of cast iron with spheroidal graphite is metallurgically and technologically very complicated. This compilation is connected with the fact that it is necessary to ensure homogeneity in all areas of the melt, not only with regard to the amount and type of modifying reagent used, but also the amount of the inoculant used is decisive. The preparation of this melt in such a large quantity corresponding to the production of machine tool parts is very important from a metallurgical point of view and very complex from a technological point of view. Both the amount of melt and the amount of modifying reagent are very sensitive to the formation of spheroidal graphite. In the case of the production of high quality cast iron with spheroidal graphite, digital scales are required in the melting and metallurgical preparation of the production to ensure that the correct amount of modifying reagent is applied to the appropriate amount of melt. If the correct amount of modifant is not applied to a given batch of liquid metal, it can be assumed that the cast iron produced may not conform to the prescribed structure. When producing large castings of cast iron with spheroidal graphite, it is also important to have a large quantity of metallurgically treated melt available for casting to produce this cast iron. As is generally known, the melt from the cupola is not very suitable for the production of cast iron with spheroidal graphite (it contains a large amount of sulphur, about 0,1 %). In this case, the melt produced, for example, in a rotary drum furnace with an oxy-gas burner with a production capacity of 12 t can be used. Nevertheless, the quality of the melt produced in this rotary drum furnace is very good, even in the case of the basic elements being burnt out. In this case, it is rather complicated to achieve the required carbon content in the furnace, especially when several ladlefuls are carried out and the cast iron has to remain for a longer time at the required temperature in the furnace. However, thanks to very good experience, the required carbon content in the cast iron melt can be maintained. This is also helped by the charge used, which consists of pig iron (30-50 %), returnable material (reject castings, gating systems, castings), scrap steel and slagging additives.

The carbon content of the melt is mainly obtained from the pig iron, but can subsequently be adjusted by means of carburizers. Ferroalloys can be added to the melt or can also be part of the charge. The length of a single smelting process varies between 90 and 180 minutes, depending on the temperature of the ladleful and the size of the smelting furnace. The furnace used is to some extent related to the durability and quality of the furnace lining with which the melt is in contact.

The maximum temperature in a rotary drum furnace - can reach up to 1550 °C, which is already very undesirable for the durability of the lining. A maximum temperature of 1480 °C in the melting furnace is recommended for the longevity of the lining.

The melt preparation for the production of machine tool parts made of cast iron with nodular graphite is carried out at 1420 °C. Once this temperature is reached, a ladleful process takes place, which includes the first inoculation of the melt directly into the metal stream using 0,2 wt.% of VP216 powdered inoculant. This inoculated melt flows into a preheated casting ladle with the required volume of 4 tonnes. Between 2 and 3 tonnes of melt are poured into this ladle. After the first inoculation into the metal stream, the temperature of the melt is measured and then the melt in the ladle is transported to the workplace where a Progelta metallurgical station is used to modify the cast iron melt with a filled profile. Next, secondary inoculation of the melt takes place. The prepared cast iron melt with spheroidal graphite has a eutectic composition.

When the above steps are carried out, it is expected that the machine tool parts produced will exhibit a cast iron with spheroidal graphite with appropriate mechanical properties.

7 Conclusion

The target of this article was to show the methodology of monitoring the quality of the produced cast iron with spheroidal graphite for the production of the WHR 13 spindle casting, which is part of a horizontal table boring machine. Due to the fact that it is a very massive casting there is a risk of defects such as shrinkage and microporosity. At the same time, it is necessary to pay attention to the development of the technological procedure and also to all the methods that can be used to determine the quality of the cast iron produced when there is no possibility of damaging the material part of the WHR 13 spindle casting. Using the QuikCAST computer software, the existing technology was upgraded to eliminate the greatest risk of casting defects. Using this upgraded technology, WHR 13 spindle castings were produced and subsequently machined and these castings no longer exhibited defects. At the same time, due to the financial demands of the innovative technology, the question of whether the occurrence of defects in the castings was due to a technological or metallurgical problem was also addressed. For this reason, the quality of the melt was monitored in cooperation with Technical Service Kuehn GmbH and DETYCON Solutions s.r.o. AccuVo thermal analysis was used for this purpose. Based on this analysis, it was found that both process and material changes should occur in the production of cast iron with ball graphite. The material changes would mainly concern the inoculation. It is also clear from the article that predicting the quality of the material casting of a spindle can be based on the determined chemical composition of the melt, thermal analysis with determination of the eutectic temperature, or mechanical property values and the microstructure of the cast iron. Despite the fact that it was possible to obtain cast iron with spheroidal graphite, the result is not ideal. Based on this measurement, it is clear that process and material changes will have to be made. The process change would then be the removal of the primal inoculation, as the measurements have shown that it is completely without effect and only makes production more expensive. A material change would be to change the chemical composition, as measurements have shown that eutectic chemical composition does not guarantee eutectic solidification. Therefore, a slightly sub-eutectic chemical composition would be suitable, the melting should then be more metallurgically controllable. A further material change could then be e.g. testing an alternative inoculant. The whole experiment should be repeated to verify the accuracy of the origin measurements before implementing process and material changes.

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