Structure Distribution in Precise Cast Iron Moulded on Meltable Model

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Abstract

Topic of this work is to compare metalurgy of cast irons poured into sand moulds and into shell molds at IEG Jihlava company and from it following differences in structures of thin- and thick-walled castings. This work is dealing with investigation and experimental measurement on surfaces and sections suitable thin- and thick-walled investment castings at IEG Jihlava. Cast irons with flake graphite (grey cast iron) and cast irons with spheroidal graphite (ductile cast iron). Both mechanical and physical properties are determined using calculations from as measured values of wall thicknesses L and Lu, Vickers hardness and remanent magnetism. Measurement results are discussed, findings are formulated and methods for castings metallurgical quality improvement are recommended finally.

Keywords: Ultrasound structuroscopy, Cast irons, Metallurgical quality, Investment casting

1. Introduction

The aim of this work is take look into relation of structure and selected physical properties to flowability and wall thickness of investment cast iron castings. The determination of these relations favourable if we want to forecast structure of products or semiproducts without their destruction.

The relation of structure to flowability and wall thickness of cast iron castings poured into sand moulds is known. It is reflected in ČSN and EN standards generally. But the investment casting technology provides quite different cooling and solidification conditions. Application of abovementioned standards for prediction of investment casting useful properties could led to non allowed errors.

The measurement of selected casting was made at least at two sites – on the wall at gate and at thinnest wall of castings from cast irons with spheroidal and flake graphite which were poured in IEG foundry shop.

The non-destructive structuroscopy was based on measurement of Vickers hardness, actual L and ultrasound thickness Lu and remanent magnetic field Hr using DOMENA B3. The limited resources for research in the frame of bachelor work [1] allowed use of castings from common commercial production. For this reason the results for description of given problem are not exhaustive but they indicate the way to further more detailed research of prediction of precious cast iron castings properties.

2. Investment casting technology

The investment casting i.e. “LOST WAX” method takes a key-position in the field of modern techniques of pouring of metals. It can be incorporated into techniques-products near to finished artefacts. The higher requirements at manufacturing are pressed for quality, surface quality, dimension accuracy, internal cleanness, higher functional parameters at strong pressure to production cost. This method belongs among progressive ones
which enable at effective application significant savings of material and reduces using finishing operations. It is used mainly where the production of part by other technology is extraordinary expensive or even impossible with regard to complicated shape and difficulty machinable material.

**Production process consists of:**
- Manufacturing of molds for patterns,
- m. of wax patterns
- setting patterns to tree,
- m. of shells, soaking of wax patterns into ceramic slurry,
- pouring of wax patterns by refractory material,
- melting out of wax,
- burning of shells,
- melting and pouring,
- finishing operations (removing of ceramics, separation of castings from gating system, cutting, grinding, inspection)

Single stages follow consecutively in this way and they can not be skipped or replaced.

The cracks of shells can remain after melting out of wax and they can be opened and they can cause cracks of casting after casting.

The molds are burnt off at 950 °C mostly to reach innertness and high stability. The application of ceramics on basis of silicates is limited by temperature 1550 °C which is close to melting point of silicate. The annealing of shells at IEG Jihlava is made in chamber furnace. The cast iron is poured into hot shells immediately after extraction from burning (annealing) furnace.

The thermal shock at pouring is reduced by it and internal stress formation in shells is limited and dangerous cracking is lowered. Induction furnaces ISTOL and tyristor sources from Indukce Co, Ltd are use at IEG Jihlava Co. The unalloyed steels and cast irons with foliated and spheroidal graphite are melted in furnace with acid lining of EKW Co. The alloyed steels are melted in furnace with neutral lining of LUSIMA - LUNGMS Co. The sample of melt is taken for chemical analysis before casting. The ceramic filters preheated to shell temperature are inserted usually into hot shells before casting.

**Melting and pouring of cast irons in IEG:**
Basic charge for production of cast irons with foliated and spheroidal graphite at IEG Co. Is pig iron PIG NOD with typical chemical composition C 4.2-4,6%, Mn less than 0.2%, Si 0.2-0.3%. Further part of charge is circulating steel scrap and circulating material from corresponding type of cast iron. The copper is used as a pearlite-forming element for cast irons with foliated an spheroidal graphite. The cast iron with spheroidal graphite is made by FLOTRET flow method with inoculation into stream of metal.

The metallurgical quality of pouring is checker by oxygen activity measurement, thermal analysis and sound speed measurement which can be applied for finished casting mainly.

**Technical parameters:** Mas sof castings 10-1000g, after agreement upto 3000g, wall thickness from 1mm, dimensions 10-150 mm, max. 220 mm. Permissible deviations of dimensions after ČSN 01 4470

**2.1. Experimental**

The subject of experiments were commercially cast castings. Each sample is marked by serial number with name of casting and casting material. The measurement with non-destructive method was made for each sample in site A (gate of melt) and in sites B, eventually C (thin and thick wall of casting). Single pictures of samples with measurement sites (A, B, C) are incorporated in Appendix of work [1]. The speed of sound \( v_L \) was measured (it characterizes the morphology of graphite, elasticity modulus, ultrasound thicknessmeter DIO 570 with probe 4MHz) [2], hardness HV (hardnessmeter Brinell-Vickers HECKER-WPM Leipzig type:HP-250) and remanent magnetic field intensity \( H_r \) [3]. Mean values of as-measured and calculated data are written-down for each sample and measurement sites to overview Table 3-5. The structure, ie. graphite distribution and its shape, pearlite and skin of casting were determined from sections of selected samples at laboratory of TU of Liberec.

Sound speed

\[
v_L = v_{L,0} \times \frac{L}{L_0} \quad \text{[m/s]} \quad (1)
\]

Initial elasticity modulus

\[
E_u = (K \cdot \frac{L}{L_0})^2 \quad \text{[MPa]} \quad (2)
\]

The constant \( K \) comprises density and Poisson number. It is determined by measuring of standard testing bars [2]. As-measured and calculated value of \( K \) for cast iron with flake graphite is \( K = 452,2 \), for cast iron with spheroidal graphite is \( K = 432,6 \) [5].

Different formulas created in the frame of work [4] are valid for calculation of \( R_m \) of cast irons with flake and spheroidal graphite.

The checking of graphite share was made using relation for melting test of nodularity at IEG foundry shop [6]

\[
GVI = 3014 \cdot \frac{L}{L_0} - 2783 \quad \% \quad (3)
\]

| CN 42 2410 | CN 42 2415 | CN 42 24 20 | CN 42 24 25 |
|-----------|-----------|-----------|-----------|
| ČSN quality | Es (GPa)  | Es (GPa)  | Es (GPa)  |
| 42 2410   | 85        | 97        | 110       | 125       |
Table 2.
Classification of graphite cast irons after shape of graphite and \( E_0 \).

| Type of cast iron                                  | Initial elasticity modulus \( E_0 \) (GPa) | Abbreviation |
|---------------------------------------------------|------------------------------------------|--------------|
| with flake graphite                               | 87-144                                   | FGI          |
| with vermicular(or compacted) graphite             | 145-160                                  | CGI          |
| with spheroidal graphite                          | 165-175                                  | SGI          |

2.2. Results

Due to the limited extent of contribution only some results are introduced.

Typical samples – Fig. 1 and 2.

Table 3.
Close correlation of HV hardness and remanent magnetism \( M \) of sample 24.

| Sample no. 24 | \( M \) [A/m] | HV       |
|---------------|---------------|----------|
| I             | 188           | 232      |
| II            | 191           | 232      |
| III           | 183           | 224      |
| IV            | 132           | 209      |
| V             | 233           | 270      |
| diameter      | 185,4         | 233,4    |
| standard deviation | 32,12849  | 20,13554 |
| correlation coefficient | 0,94483969 |         |
Table 4.
Eo values in walls of samples of cast iron with foliated graphite

| sample no. | name of casting | material after ČSN | measurement site | actual thickness L/mm/ | ultrasound thickness L_u/mm/ | sound speed v_L (m/s) | Eo (MPa) calculated | Corresp. ČSN | dEo |
|------------|----------------|---------------------|------------------|------------------------|----------------------------|----------------------|-------------------|----------------|------|
| 4          | Fork           | 42 2425             | A /Gate/         | 101,7                  | 134,2                      | 4484                 | 117 435           | ČSN 42 2425    |      |
|            |                |                     | B                | 4,6                    | 5,4                        | 5043                 | 148 385           | ČSN 42 2425    | 31   |
| 7          | Cock           | 42 2420             | A /Gate/         | 33,85                  | 43,5                       | 4606                 | 123 823           | ČSN 42 2420    |      |
|            |                |                     | B                | 7                      | 8,7                        | 4763                 | 132 379           | ČSN 42 2420    | 9    |
| 14         | Lifter body    | 42 2420             | A /Gate/         | 21,67                  | 30                         | 4276                 | 106 693           | ČSN 42 2415    |      |
|            |                |                     | B                | 1,6                    | 1,9                        | 4985                 | 145 009           | carbides       | 38   |
| 21         | Cock           | 42 2420             | A /Gate/         | 34                     | 43,3                       | 4648                 | 126 079           | ČSN 42 2420    |      |
|            |                |                     | B                | 1,5                    | 5,1                        | 5074                 | 150 234           | Carbides       | 24   |

Table 5.
Sound speed and shape of graphite of sample no. 24, arresting member

| sample no. | name of casting | material after ČSN | measurement site | actual thickness L/mm/ | ultrasound thickness L_u/mm/ | sound speed v_L (m/s) | GVI% | dGVI thin-thick wall (gate) |
|------------|----------------|---------------------|------------------|------------------------|----------------------------|----------------------|------|---------------------------|
| 24         | Arresting member I | 42 2305            | A / Gate /       | 15,25                  | 16,47                      | 5481                 | 7,74 |                           |
|            |                   |                     | B                | 3,2                    | 3,4                        | 5571                 | 53,7 |                           |
|            | Arresting member II | 42 2305           | A / Gate /       | 15,23                  | 16,69                      | 5402                 | GIII |                           |
|            |                   |                     | B                | 3,22                   | 3,41                       | 5590                 | 63,06 |                           |
|            | Arresting member III | 42 2305          | A / Gate /       | 15,23                  | 16,47                      | 5474                 | 4,08 |                           |
|            |                   |                     | B                | 3,22                   | 3,4                        | 5606                 | 71,43 |                           |
|            | Arresting member IV | 42 2305          | A / Gate /       | 15,27                  | 16,29                      | 5549                 | 42,27 |                           |
|            |                   |                     | B                | 3,22                   | 3,41                       | 5590                 | 63,06 |                           |
|            | Arresting member V | 42 2305           | A / Gate /       | 15,27                  | 16,29                      | 5542                 | 38,57 |                           |
|            |                   |                     | B                | 3,23                   | 3,4                        | 5624                 | 80,3  |                           |
Table 6.
Elasticity modulus $E_o$ and strength limit $R_m$ for castings from cast iron with spheroidal graphite

| sample no. | name of casting | material after ČSN | measurement site | actual thickness L/mm/ | HV hardness | $E_o$ (MPa) calculated | $R_m$ (MPa) calculated |
|------------|----------------|-------------------|------------------|------------------------|-------------|-----------------------|-----------------------|
| 1          | Nipple         | 42 2304           | A / Gate /       | 6,9                    | 250 HV      | 169 628               | 761                   |
|            |                |                   | B                | 4,2                    | 240 HV      | 169 706               | 702                   |
|            |                |                   | C                | 1,98                   | 221 HV      | 166 366               | 651                   |
| 2          | Lever          | 42 2306           | A / Gate /       | 18                     | 248 HV      | 167 962               | 737                   |
|            |                |                   | B                | 10,1                   | 309 HV      | 176 502               | 1014                  |
| 3          | Holder         | 42 2304           | A / Gate /       | 4,38                   | 272 HV      | 155 826               | 655                   |
|            |                |                   | B                | 13,2                   | 193 HV      | 164 015               | 558                   |
| 4          | Guiding head   | 42 2304           | A / Gate /       | 15                     | 275 HV      | 168 671               | 814                   |
|            |                |                   | B                | 5                      | 242 HV      | 173 024               | 780                   |
| 5          | Lever          | 42 2304           | A / Gate /       | 12,1                   | 195 HV      | 164 651               | 568                   |
|            |                |                   | B                | 7,4                    | 201 HV      | 164 441               | 619                   |
| 6          | Splice plate   | 42 2304           | A / Gate /       | 7,1                    | 270 HV      | 172 277               | 847                   |
|            |                |                   | B                | 6,3                    | 242 HV      | 170 516               | 750                   |
| 7          | Pin            | 42 2304           | A / Gate /       | 10                     | 348 HV      | 146 560               | 689                   |
|            |                |                   | B                | 4,6                    | 252 HV      | 179 264               | 886                   |
| 8          | Inserting ring | 42 2304           | A / Gate /       | 12                     | 252 HV      | 161 941               | 678                   |
|            |                |                   | B                | 22,2                   | 198 HV      | 165 598               | 585                   |
|            |                |                   | C                | 12                     | 270 HV      | 175 264               | 886                   |
| 12         | Pad            | 42 2306           | A / Gate /       | 14,3                   | 227 HV      | 167 838               | 681                   |
|            |                |                   | B                | 14,3                   | 272 HV      | 174 712               | 885                   |
| 13         | Lever          | 42 2304           | A / Gate /       | 19,8                   | 255 HV      | 161 713               | 683                   |
|            |                |                   | B                | 15,5                   | 234 HV      | 161 214               | 629                   |
| 14         | Key            | 42 2304           | A / Gate /       | 5,6                    | 165 HV      | 152 674               | 404                   |
|            |                |                   | B                | Not measured           | 223 HV      | Not calculated        | Not calculated        |
| 15         | Holder         | 42 2304           | A / Gate /       | 29,4                   | 198 HV      | 157 967               | 517                   |
|            |                |                   | B                | 8                      | 198 HV      | 158 239               | 513                   |
| 16         | Needle bar holder | 42 2304         | A / Gate /       | 11,6                   | 263 HV      | 169 188               | 790                   |
|            |                |                   | B                | 7,7                    | 232 HV      | 182 375               | 864                   |
| 17         | Pestie         | 42 2304           | A / Gate /       | 25,3                   | 235 HV      | 169 298               | 1051                  |
|            |                |                   | B                | 25,3                   | 239 HV      | 173 182               | 1116                  |
|            |                |                   | C                | 6,5                    | 228 HV      | 181 515               | 1262                  |
| 18         | Plunger        | 42 2304           | A / Gate /       | 23,7                   | 252 HV      | 172 296               | 799                   |
|            |                |                   | B                | 10                     | 252 HV      | 169 744               | 768                   |
| 19         | Termination    | 42 2304           | A / Gate /       | 21                     | 160 HV      | 164 481               | 478                   |
|            |                |                   | B                | 22,2                   | 233 HV      | 169 890               | 973                   |
| 20         | Stand          | 42 2304E          | A / Gate /       | 8,4                    | 315 HV      | 178 540               | 1062                  |
|            |                |                   | B                | 10                     | 315 HV      | 179 876               | 1083                  |
| 21         | Wing           | 42 2304           | A / Gate /       | 4,8                    | 301 HV      | 165 774               | 841                   |
|            |                |                   | B                | 26                     | 242 HV      | 167 284               | 714                   |
3. Conclusions

This contribution is dealing with selected knowledge from experiments on 24 castings of various types of cast iron manufactured in frames of common production of foundry shop of precision casting. FGI castings (cast iron with flake graphite) contain ledeburitic carbides in walls up to 5 mm thickness except of gate. Their presence is indicated reliably by ultrasound measurement (enhanced value of sound speed). On the contrary the dangerous carbides can not be discovered by hardness values – high hardness of carbides is eliminated by enhanced share of ferrite in cast iron matrix of as – investigated parts of castings. Austenitic GJL (NIREZIST) solidified with carbon bound in carbides without graphite.

The upper limit of allowed hardness is practically always exceeded at ferritic cast iron with spheroidal graphite (200 HB for quality after ČSN 42 2304) at gate and in thick wall as well. Upper hardness value in thin wall against the gate of casting is not natural for GJS. GJS rigidity is least at gate always. Collective mathematic models for magnetic hardness measurement and ultrasound rigidity measurement of $E_0$, %GVI can not be used. It is necessary to create mathematic models for calculations of HB hardness, $E_0$, %GVI rigidity and $R_m$ tailored for certain types of castings.

The subject of further research will be taking account of effect of position on pouring tree on mechanical properties.

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References

[1] Suchomel, J. (2013). Rozložení struktury v přesných litinových odlitcích [Structure distribution in precision cast iron castings at investment casting]. Bachelor Thesis KMT-B-209, TU of Liberec, Faculty of Mechanical Engineering, Liberec, CZ.
[2] Skrbek, B., Bílek, D. (2013). Akustická a metalografická charakteristika grafitu litin [Acoustic and metallography characteristics of cast irons graphite]. In: 43rd Int. Conf. Defektoskopie (2013). NDE for Safety. Brno: Czech Society for NDT, 2013, p.159-164. ISBN 978-80-214-4799-8.
[3] Skrbek, B. (2008) Metoda magnetické skvrny [Magnetic spot method]. Liberec: Technical University of Liberec, 2008. ISBN 978-80-7372-428-3.
[4] Skrbek, B. (2014). Combined nondestructive structuroscopy of dispersion metallic materials. In: 11-th ECNDT 2014, Praha, [CD ROM], p.484. ISBN 978-80-214-5635-6.
[5] Obraz, J. (1989). Zkoušení materiálu ultrazvukem [Material testing by ultrasound]. 1-st Edn., SNTL: Praha.
[6] Skrbek, B., Policar, K. (2009). Problematiky of Material Quality and Precision Casting Manufacturing from Cast Iron with Spherical Graphite by Investment Casting Technology. In: Sborník vědeckých prací Vysoké školy báňské Technické univerzity Ostrava [Transactions of the VSB - Technical University of Ostrava]. Contribution 09, issue 1, 2009, vol. I II, Series Metallurgy.