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Verification of Modification Effect on Prototype Castings from GJV Using Ultrasound Checking

B. Skrbek [a]*, O. Bouška[b], K. Nedělová [b], J. Heunisch [b]

[a] Technická univerzita v Liberci, fakulta strojní, katedra materiálu, Studentská ul. 2, Liberec 461 17, Česká Republika
[b] Slévárna HEUNISCH Brno, s.r.o. Brno, 628 00, Zaoralova 1
*Corresponding author. E-mail address:bretislav.skrbek@tul.cz

Abstract

Reason for and risks of using of cast iron with vermicular graphite for typical construction parts. Ultrasound checking of graphite shape. Factors influencing plausibility of result. Difference between laboratory and operation application. Roughness, parallelism, stability and size dimension of walls. Conditions, proposals for simplification and productivity enhancement of castings checking. Recommendation.

Keywords: Cast iron with vermicular graphite, Ultrasound checking of structure, Plausibility of results

1. Introduction

The modification effect of cast iron with compact graphite is usually verified by testing a specially cast as-cast specimen. Various methods such as spectrum analysis of residual Mg content, thermal differential analysis, oxygen activity determination, metallography or ultrasound rapid test are used for operation evaluation of modification efficiency evaluation. The model equipment with prototype body and technology tests was made to enable testing of process parameters effect on metal structure obtained. Different cooling velocity was reached at technology test of stepped wedge and solidification of thin- and thick-walled castings was represented. The solidification in thin-walled added samples is used for verfication of modification of sheroidal graphite cast iron castings.

Such tests are satisfactory for modification verification of castings of cast irons with spheroidal graphite. The failed modification in the thicker wall of casting need not be detected in the specimen casting. The modification efficiency must be checked just in a chosen place of the casting. The checking of the total production of castings requires rapid measurement without surface treating.

This contribution quantifies surface roughness effect on elasticity modulus measurement accuracy of cast irons with flake graphite and share of vermicular graphite of cast irons of type EN GJV and GJS.

2. Utilization and checking of cast iron with vermicular graphite

Mechanical stresses created at non-uniform cooling (or decelerated thermal dilatations) and heating of various parts of one component, can lead to permanent deformations at a given temperature and then to thermal fatigue. The resistance against this loading can be characterized by the Eichelberg factor EF.

$$EF = R_m \times \lambda \ \square\square / (\alpha \times E), \quad [W/m] \tag{1}$$

where

λ - thermal conductivity,
α - linear expansion coefficient,
E - elasticity modulus.

The material resistance against thermal fatigue increases with higher EF value (metalic moulds, heads of cylinders, exhaust pipelines, cases of turbo-blowers, brake and clutch wheels). The cast irons with vermicular graphite have the highest value of EF among ferrous alloys esspecialy. They are alloyed with Si up to 5 % and Mo up to 1 % for exploitation at temperatures closely below A1 transformation. Other applications of vermocular cast iron: Castings from cast iron of type GJL, which do not satisfy with strength at innovation and design, cannot be change. Research and development of axle bodys and housings from vermicular cast iron – project, to which is dedicated this contribution. The efficient reproducibility of cast iron with vermicular cast iron castings can be achieved at large series manufacturing with stabilized raw basis and reliable checking.

2.1. Interaction of graphite cast iron structure with acoustic waves

Transmisivity of acoustic waves through material decreases with damping of matrix matter and namely with quantity and size of internal discontinuities. As a discontinuity inclusions with considerably different resistance Z against matrix can be considered [2].

$$Z = c \times \rho \quad [MPa/s] \qquad (2)$$

The amount and quantity of reflectance R increases with increasing difference of acoustic resistances Zm and Zg from boundary back

$$R = (Z_g - Z_m)/(Z_g + Z_m) \qquad (3)$$

For steel matrix of cast iron is valid Z_m=5,92×7,2=46,2 MPa/s.
For graphite is approximately valid $Z_g = 2 \times 2 = 4$ MPa/s.
Boundary matrix - graphite reflects R= 80,5% of pressure of accoustic wave. Direct propagation of acoustic wave through the cast iron is after several reflections from graphite formations spent and dispersed. The size of the path of the acoustic wave through matrix depends on the labyrinth of graphite formation. With increasing weakening of matrix by graphite formation increases the value of accoustic path Lu in comparison with direct

path (thickness of wall) L. Sound velocity c_L sink the following way.

$$c_L = c_{L0} \times L/L_u = 5920 \times L/L_u \quad [m/s] \qquad (4)$$

where
c_{LO} - rsound velocity of castiron steel matrix.

If in a rapidly cooled part of casting metastable crystalization of eutectics occurs (it means that carbon instead of deposition in the form of graphite binds to iron forming carbide Fe3C and suspends as a hard ledeburite) then occurs fewer obstacles against the propagation of the acoustic wave and for this reason sound velocity value increases with increasing amount of ledeburite in the structure.
Amplitude damping of accoustic oscillations α increases markedly if wavelength λ approaches the size l of graphite formations [1]

$$\alpha = \square k_f \times l \times (c_L \square \lambda)^2 \quad [dB/mm] \qquad (5)$$

Value α=0,05 for steels enables sound through even one-metre wall thicknesses. Graphite increases damping markedly. For cast iron with flake graphite reaches values of greater order which very much restricts fault detection. Most of the castings can be characterized by intrinsic resonance f_r, which is the function of elasticity modulus E (it describes shape of graphite), specific weight (amount of graphite) and geometry slenderness H/D. Frequency f_r can be found usually in the audible extent [7]

$$f_r = k_f \times (E/\rho)^{0,5} \times D/H^2 \quad [Hz] \qquad (6)$$

E value depends directly on size of sound velocity c_L thus on shape and amount of graphite [1].

$$c_L = \{(E/\rho) \times (1 - \mu)/[(1+\mu \square \times (1 - 2 \times \mu)]\}^{0.5} \quad [m/s] \square \qquad (7)$$

By modification (7) can obtain simplified where L is true wall thickness and Lu wall measured by ultrasound

$$E = (K \times L/L_u)^2 \quad [MPa] \qquad (8)$$

EN standards are not unambiguous at assigning Eo values. Value 160 GPa corresponds to 25-35% share of vermicular GIII at the expense of spheroidal GVI graphite in cast iron structure. E.g. strict TP 22-112-04 requires to keep limit value 170 GPa.

Table 1.
Example of values of initial elasticity modulus Eo of cast irons after Czech standards and sound velocity

ČSN quality	Eo [GPa]	C_L [m/s]	L/Lu
42 2304,5 (GJS EN)	**160**	**5475**	**0,9247**
42 2306,7	**170**	**5642**	**0,9532**
42 2430 (GJL EN)	**144**	**4819**	**0,854**
42 2425	**125**	**4795**	**0,81**
42 2420	**110**	**4500**	**0,76**

Table 2.
Composition of cast irons

Content %	C	Si	Mn	P	S	Mg	Cu	Cr	SE
GJL	3,3	1,94	0,85	0,117	0,116	0	0,21	0,06	0,916
GJV	3,34	3,1	0,18	0,027	0,014	0,014	0,23	0,04	1,014
GJS	3,3	2,45	0,25	0,02	0,015	0,046	0,04	0,03	0,946

Table 3.
Surface roughness in μm.

surface	Ra	Rmax	Label
brushed	24-35	150-236	K
shot blasted	16-23	90-160	T
milled	4,5-7,4	37-57	F

Table 4.
Results. Relative velocity $v_r = L/Lu$ stated 1000 times greater

L mm	GJL			GJV				GJS			
	V_{rb}	V_r	dV_r	V_{rb}	V_r	dV_r	dV_L m/s	V_{rb}	V_r	dV_r	dV_L m/s
5,5											
k	803	682	121	922	820	102	603,84	958	853	105	621,6
t	809	734	75	932	853	79	467,68	969	900	69	408,48
f	798	786	12	924	911	13	76,96	962	948	14	82,88
12											
k	825	756	69	912	863	49	290,08	961	911	50	296
t	819	799	20	909	889	20	118,4	963	939	24	142,08
f	822	816	6	915	910	5	29,6	960	956	4	23,68
22											
k	793	771	22	903	884	19	112,48	958	940	18	106,56
t	805	795	10	901	892	9	53,28	954	947	7	41,44
f	802	800	2	905	902	3	17,76	956	953	3	17,76
43											
k	787	773	14	898	886	12	71,04	950	939	11	65,12
t	803	797	6	902	897	3	17,76	952	948	4	23,68
f	809	808	1	901	899	1	5,92	951	950	1	5,92

2.2. Shape and size of graphite

Steps at ultrasound structuroscopy development [3]:
1. Informations about pouring metallurgy and temperature mode of castings. Place of checking.
2. Pouring of wedges with high share of GIII (over 30%), without modification, overmodification (share of Cm over 10%).
3. Non-destructive measurement of specimens
4. Metallography tests of wedges.
5. Creation of mathematical models, recommendation of technique.
6. Creation of manufacturing documentation (Instructions for technical checking).
7. Verification of models and training of technical check workers

Example of ultrasound checking of GVI graphite amount of castings poured by precise casting method (lost wax). The wall legth L 39,964 mm is changed only with standard deviation 0,03mm. For this reason its fluctuating can be neglected and only Lu value can be measured at operation checking. The following relation was created from experimental

$$GVI = 2683 – 66,06 \times Lu, \quad \%, \quad K = 0,974 \tag{9}$$

The expression (9) serves to operation checking. The neglecting of dimension L changes brings the error in GVI determination 4%.

The ultrasound diagnostics of graphite shape requires parallel wall areas in checking place. The value of as-measured Lu is enhanced by surface roughness (amount of binding medium) and „V" effect of ultrasound probe on thin walls, so that to check walls upto L 10mm is illusory. For this reason the „MAT" method was developed for thinwalled castings [5].

2.3. Surface roughness

During the experiment were exploited parts of flat samples of three types of cast irons (LLG = GJL; LVG = GJV; LKG = GJS) with four thicknesses (on average 5,5; 12; 22; 40mm) and three surface treatments (only brushed as-cast surface – K; shot blasted (cca 0,5mm) from hardmetal– T; milled – F. The reference level of roughness is created by as-grinded surface Ra 1,1 (emery paper smirkový of dispersion 80). The chemical composition is given in Table 2. Casted in a sound mould without special paints. Because of limited extent of this publication the mean values and ranges of values are mentioned and no all results. The wall thickness L was measured by digital caliper rule MITUTOYO and ultrasound thickness L_u by defectoscope DIO562 with double probe PN10-2C (d 10mm, 2 MHz). The final echo was set to height 100 % of display and monitor to 15 % of display height at measuring with sensitivity change. The contact acoustic bond was arranged by gel VG-1.
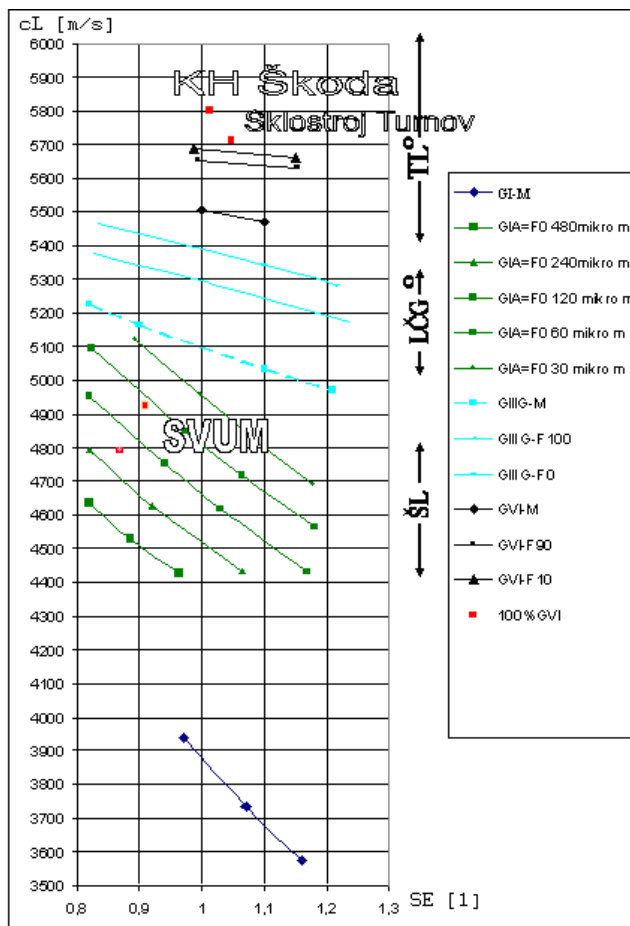

Fig. 1. Effect of graphite morphology and eutectic ration SE on sound velocity. M – martensite, F – ferrite. GIII and GVI with size 5. ŠL = GJL, LČG=GJV, TL=GJS ; c_L = v_L

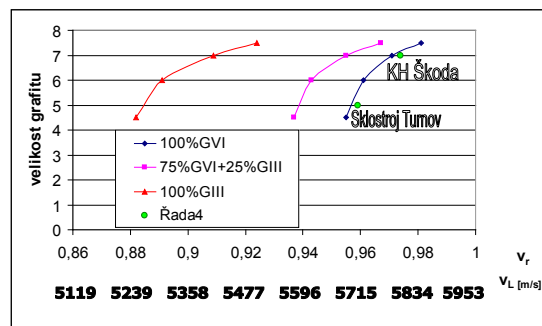The sound velocity is influenced by globular graphite dispersion as well.

Fig. 2. Dependence of graphite size after EN (larger size numer means smaller grains GVI or GIII graphite formations) on sound velocity.

From graph 2 was set following equation for 100%GVI

$$velGVI=-4845,8x(Lu/L)^2+9492,2xL/Lu-4640,9 K=0,9896 \qquad (10)$$

The roughness size was valued by maximum R_{max} aand mean R_a value. The roughness meter used was TR110 PTS Solnař Ostrava. The delay of ultrasound probe front from metallic surface of casting is given just by R_{max} value. The sound velocity in bonding gel is c.a. 1500m/s – one quarter of sound velocity in steel. The space fulfilled with gel between tips R_{max} on unevenness and metallic surface is read to L_u -- nearly four times. With a rougher surface, lower as-measured relative v_r,and absolut v_L sound velocity can be expected. The differences dv between velocities v_r as-measured on reference and rough surface (signed K, T or F) are given in tables and graphs. These differences are expressed for cast iron with flake graphite by difference of initial elasticity modulus value E_o in MPa and for cast irons of type GJV and GJS by deviation in as-measured content of GIII or GVI in %. The reference value was obtained by sound velocity measurement after grinding of originally rough surfaces of samples. The unfavourable effect of non-parallelity and curvature of opposite surfaces of as-measured casting wall will be quantified in following publications. The similar effect on sound velocity can be assigned to painting layers. 0,1mm basic paint has the same impact on L_u value like 0,35mm of cast iron.

Following expression can be used for calculation of initial elasticity modulus [4].

$$E = (437,8 \times L/L_u)^2 \quad [MPa] \qquad (11)$$

The sound velocity change approximately 30 m/s corresponds to difference of GVI(5) content [3].

3. Disscusion

The technical conditions of cast iron with spheroidal graphite castings require minimum content of GVI and GV 80-85%. The limit of content of GIII in cast irons with vermicular graphite castings must be connected with wall tickness. The greater share of spehroidal graphite GVI is precipitated in thinner walls. But flake graphite GI must not be precipitated (max.3%).

The graphite size effect on reliability of the limit of contents of GIII determination at assumption constant eutectic ratio follows from Figures 1 and 2: The difference of c_L values between GIA 5 and 7 is about 300m/s (cast irons GJL); for GIII 5 and 7 about 130 m/s (GJV) and for GVI5 and 7 about 80m/s (GJS).

The c_L extent 130 m/s at constant size of GIII corresponds to change greater than 30% of its content in the structure of vermicular cast iron.

The change 0,1 in value of eutectic ratio SE means the change of c_L about 130 m/s at constant size of GIA, 50 m/s at constant size of GIII and 15 m/s for GVI. The unfavorable effect of roughness on share measurement of certain shape of graphite in structure is quantified by following graphs.

The difference of Eo values corresponding to adjacent quality classes (e.g.. GJS 200 and GJS 250) is about 15000 MPa The deviation greater than 5 GPa at measurement of E causes roughnes a) for wall thickness up to 4 mm and as-milled surface, b) for wall thickness up to 12 mm and shot blasted surface and c) for wall thickness up to 28 and not blasted surface.
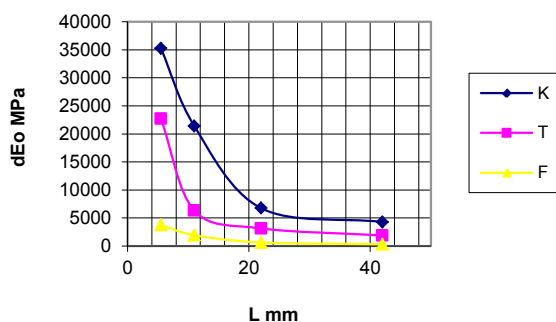
GJL, Rmax, UT Eo

Fig. 3. Error increasing at elastic modulus value determination by ultrasound with decreasing casting wall thickness L of cast iron with flake graphite

GJV

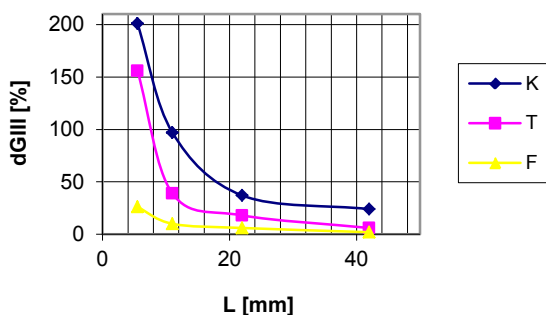Fig. 4. Error increasing at determination of GIII amount value with decreasing thickness L of casting wall from cast iron with vermicular graphite
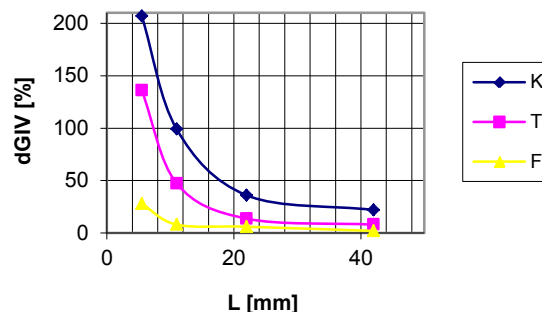
GJS

Fig. 5. Error increasing at determination of GIII amount value with decreasing thickness L of casting wall from cast iron with spheroidal graphite

A deviation greater than 10 % at GIII amount determination for as-milled surface can be measured on walls with thickness up to 10 mm, for shot-blasted surface up to 30 mm and for not blasted surface over 50 mm. The roughness R_{max} of castings of dedicated project were stated from 75 to 88 μm. The deviation at GIII amount determination greater than 10% shall be reached in walls with thickness upto 22 mm (mean values R_{max} from Table 3 considered).

4. Conclusions

The amount of precipitated graphite GIII can be evaluated objectively supposing stable size of graphite formations and eutectic ratio SE. It is necessary to introduce classification of graphite size GIII. I recommend measuring at one checking point and inoculate reproducibly. The indication of low GI graphite content cannot be performed at precipitation of too fine graphite GIII. The graphite description in cast iron by shape, size and amount (se) is useful for metallurgists, but it has no importancy for designers. The shape, size and graphite amount commonly influence cast iron rigidity, which can be specified by elasticity modulus E. E can be easily be measured by ultrasound contrary to GII share (expressions (8, 11)). The actual E values can be exploited by the designer according to his calculations.

The roughness of casting surface deteriorates GIII share measurement accuracy over untreated (by grinding) surfaces fundamentally, if contact accoustic bond of ultrasound probes is used. To check GIII amount of walls with thickness from 20 to 25 mm thick, it is necessary to take into account correction to surface roughness. The great series production ensures narrow tolerance of roughness.

The unfavourable effect of roughness on measurement accuracy of both GIII amount and E values can be depressed by immersion accoustic bond (over liquid column). If the couple of probes placed against as-measured areas of casting walls used instead of double or simple direct probe, the measurement of L will not take place and the modification effect of checking on the casting becomes more efficient.

Acknowledgements

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