EVALUATION OF MECHANICAL PROPERTIES AND DEFECTS IN CAST IRON CASTINGS BY ULTRASONIC METHOD

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ABSTRACT

Necessity to substitute impact and hardness tests by non-destructive methods especially for mass production is substantiated by short survey and analysis of modern methods for determination of cast iron mechanical properties (σ_B , $\sigma_{0,2}$, HB and others) and experimental data about spread of these properties values in castings. Theoretical substantiation of ultrasonic speed utilization is given for hardness and strength control of cast iron on the base of correlation between them. Data about influence of surface roughness and castings configuration, wave length, frequency and structural constituents size on revealing inner defects are given as well just as the results of ultrasonic industrial control of mechanical properties and castings flaw detection in metallurgical equipment, engines, machines and tools made of cast iron with flake, vermicular and spheroidal forms of graphite.

KEYWORDS

Castings, cast iron, graphite, hardness, strength, defect, ultrasonic speed and damping.

ANALYSIS OF OPTIONAL AND DESTRUCTIVE TESTS

Weight reduction of machines bringing to growth of exploitation stresses and increasing danger of premature failure lay higher claims to reliability of methods for prediction of machines efficiency and construction materials tests. Methods for mechanical tests of castings are realized according to GOST 27208-87, while quality control, grade assessment and methods for making specimen blanks are performed according to GOST I4I2-85, GOST 7293-85 and GOST 7769-82 etc. According to technical requirements to the castings optional or detailed control of structural and mechanical properties is performed. At optional control 2-3% of castings from the batch or total quantity undergo the HB test, while σ_B test is performed at samples from each melt or samples cut out of the castings with corresponding wall thickness. Optional control doesn't exclude passing-through of defective castings. There are about 25% of castings with high HB, low workability and must be annealed, the rest of them are of low quality cast iron, but all batch of castings is annealed. At detailed control HB and σ_B are determined on the samples from each specimen filled with each casting. In this case requirements to the surface quality and rupture according to GOST 27208-87 cannot be always realized as slight defects on the specimen working surface disappear after machining while careful control of fracture in conditions of mass production is not performed. 22% of the analyzed 300 tests of specimens of high-strength cast iron had complex-relief fracture with tear-out. 25% of grey cast iron samples had displacement of fracture from minimal section. Availability of invisible defects and structure heterogeneity in samples promote their low mechanical properties and not comformable to their true properties and consequently creates necessity to repeat quality control.

Hardness measurement by Brinell according to GOST 24805-8I must be performed on the surface of sample preliminarly machined to the depth of not less than 2.0 mm with Ra 2.5 mkm roughness. Machining removes the chilled liner what distorts results of measurements. Accuracy of HB measurements on stationary instruments depends upon availability of plane-parallel surfaces in castings and possibilities of their machining (stripping). It's impossible to perform it on large-sized castings. In such cases measurements are realized on cut off specimens or with portable instruments on the basis of data processing of numerous measurements. Measurement errors increase with non-compliance with requirements to controlled surfaces quality, neglecting subjective factors in dent diameter determination and use of conversion tables.

HETEROGENEITY OF CAST IRON CASTINGS STRUCTURE AND PROPERTIES

Heterogeneity of structure and chemical composition are inherent in cast irons while there are no stability of mechanical and physical properties in them. Mechanical properties of cast iron of any type or grade in the part depend substantially on its wall thickness and to be more exact on rate of cooling. So with increase of thickness from 4 to I50 mm for GS 20 GOST I4I2-85 σ_B decreases from 270 to I20 MPa (44.4%). For unalloyed perlite modified Mg cast iron σ_B drops from 600 MPa to 468 MPa (22%) with increase of wall thickness of castings from 25 to I00 mm while σ_B diminishes to 422 MPa (29.7%) with increase of wall thickness to 200 mm. Quantitative characteristics of structure heteroge-

neity degree and cast iron properties in castings are determined by numerical values of HB hardness along their cross-section and perimeter. According to experimental data hardness value variation of low-alloy GC roll castings at the same distance from the surface can make from 6 to I2% of the absolute hardness value. Hardness of GC depends upon cross-section of the casting, carbon and silicon content and increases from the runner to the opposite side of the casting.

Stress-strain properties of cast iron determined by specimens taken from wobbler, wedge and round samples according to the standards not always reflect properties of metalls in castings. Thus with increase of casting wall thickness from 20 to 80 mm σ_B ratio of casting to σ_B ratio of wobbler sample decreases from I.0 to 0.83 (Litovka V.I.,I987). For wedge sample maximum difference between HC 45 GOST 7293-85 crankcase casting and specimen make I6.2%.

THEORETICAL PREREQUISITES FOR HB AND ULTRASONIC TESTS

Non-destructive methods and especially ultrasonic one are widely used for structure, hardness and strength control of steel and cast iron castings nowadays. This method is widely used in industry not only for detection of defects in materials, articles, weld-seams, but for concrete strength control according to GOST I7624-87, determination of macro- and microstructure (form and size of graphite), evaluation of cast iron stress-strain properties in castings (Richter Hans Ulrich, I988) and others. Elastic properties of solid bodies are connected analitically with ultrasonic speed by equation

$$S^2 = E(1-\mu)/\rho(1+\mu)(1-2\mu) \quad (I)$$

where S is ultrasonic speed, mps; E - elastic modulus, Pa; ρ - density, kg/m^3; μ - Poisson's ratio.

Investigations carried out by Abe Toshihiko et al.(I985) proved that this dependence can be used for estimation of cast irons with flake, vermicular and spheroidal forms of graphite on the basis of acoustic measurements. Strength properties of materials have no such relationship and can be controlled on the basis of correlation bonds determined experimentally. Mechanical stresses during determination of hardness depend on E and μ too (Ivanushkin E.S., I982):

$$HB = 2K_1 / \{ n K_2 (K_2 - \sqrt{K_2^2 - 4\varepsilon_0^2 [3/8 \cdot (1-\mu^2)/E \cdot K_1 K_2)^{2/3}]} \} \quad (2)$$

Stress corresponding to the collapse load and preceding failure is connected with E and HB:

$$\sigma_B = K \cdot E \cdot HB \quad (3)$$

Comparison of expressions I, 2 and 3 shows that S just as HB and σ_B depend mainly on the same values E and μ and therefore S can be used as a criterion for evaluation of material hardness and strength. However functional relations between σ_B , HB and S suitable for practical application have not been received yet. For example, cited by Botaky A.A. et al.(1983) relation between material strength σ_p , speed S and density

$$\sigma_p = K \cdot \rho^2 S^4 / \gamma \qquad (4)$$

where K and γ are coefficients, is approximated and to the author's opinion can be useful only for qualitative explanation of relationship between ultimate tensile stress and ultrasonic speed. At the same time HB, σ_B and S of cast iron depend on structure of metallic matrix, form, quantity and dispersion of graphite. Fig. I shows experimental dependence of S upon σ_B and $\sigma_{0,2}$ what proves that with change of graphite form from spheroidal to vermicular and flake graphite decrease of σ_B , $\sigma_{0,2}$ and S takes place.

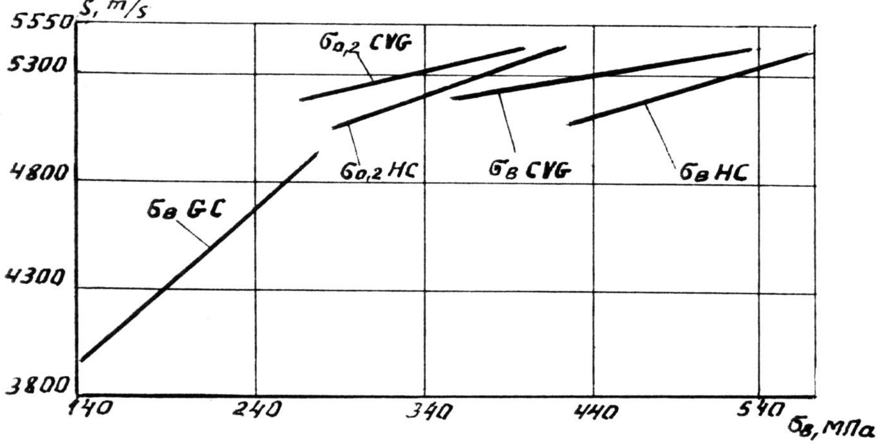

Fig. I. σ_B and $\sigma_{0,2}$ influence of GC, CVG and HC on speed S.

Influence of perlite, ferrite and cementite quantity upon S is traced with invariable content of carbon and graphite form. There is 5 to 10% more S in perlite metallic matrix than in ferrite, increase of cementite content rises S. Determining cast iron HB and σ_B by ultrasonic speed it is necessary to take into account the influence of eutecticity degree or carbon equivalent which also change S. It is stipulated by the fact that chemical composition (eutecticity, carbon equivalent) and wall thickness (rate of cooling) determine the structure of cast iron matrix and graphite form. Hardness depends on matrix while σ_B depends on matrix and graphite form.

Ivanushkin E.S. (1982, 1984, 1988, 1990) determined correlation bods between HB, σ_B , $\sigma_{0,2}$ and ultrasonic speed S des-

cribed by equations:

for grey cast iron: $HB = 10.91 \cdot 10^{-2}\, S - 271.9$ (5)

$\sigma_B = 12.6 \cdot 10^{-2}\, S - 350$ MPa (6)

for alloyed grey cast iron in rolls:

SPHN50 - $HB = (S - 3481)/4.78$ (7)

$LPHN_d$ - $HB = (S - 886)/63.86$ (8)

for cast iron with vermicular graphite:

$\sigma_B = 78 \cdot 10^{-2} S - 3735$ MPa (9)

$\sigma_{0,2} = 36 \cdot 10^{-2} S - 1232$ MPa (10)

for high-strength cast iron:

$\sigma_B = 357 \cdot 10^{-2} S - 1383$ MPa (11)

$\sigma_{0,2} = 301 \cdot 10^{-2} S - 1232$ MPa (12)

for low-alloyed cast iron with spheroidal graphite in rolls:

SShHN - 45.48 - $HB = (S - 4923)/2.05$ (13)

High correlation coefficients $r_{xy} = 0.98$; $r_{xy} = 0.95$ were obtained for alloyed grey cast iron in rolls what shows that there is a close link between stress-strain properties and ultrasonic speed near to functional. For the rest of the cast irons values $r_{xy} = 0.79 - 0.88$. Correlation coefficients are higher and links between HB and $\sigma_{0,2}$ on the one hand and speed S on the other.

FACTORS INFLUENCING DETECTABILITY OF DEFECTS BY MEANS OF ULTRASOUND

Reliability of ultrasonic estimation of castings defectiveness depends upon heterogeneity of structure and properties as well as roughness and curvature of surface. Attenuation of ultrasound in non-uniform structures attains large value at $d/\lambda \approx 1$, where d is a structural constituent size (graphite); λ is a wave length. Metallographic and acoustic characteristics of cast irons satisfy indispensable conditions of control on the whole when $d/\lambda \ll 1$. For example for HC castings on the frequency of 5 megs d/λ - 0.05; for CGG - 0.151; for GC - 0.17. On the frequency of ≤ 2.5 megs this ratio is less and inner defects with dimentions equal to λ or even bigger can be detected. Ultrasonic flaw detection (USD) of HC and CGG castings is more effective than for GC because of graphite lamellas influence. The less is the casting wall thickness, the higher is hardness, the easier it is to detect inner defects.

Another indispensable condition for USD is fettling of ultrasonic imput surface. Modern casting methods make it possible to get castings with clean, flat and smooth surface. At any frequency reflection of US waves is possible, if the groove depth is $\leq 1/3\ \lambda$, rough surfaces disperce them. Cast surfaces R_z 437 mkm and machined R_z 367 mkm don't satisfy this condition only on the frequency of 5 megs, they satisfy it on lower frequencies. At frequencies ≤ 2.5 megs converter construction influences detection of defects. Thus casting control by direct converters Ø 30 mm on the frequency of I.25 megs is necessary to perform at R_z I57 mkm. In this case minimal size of detected defect will be > 4 mm. At castings control on their surface with curvature radius $R_{curv.}$ 200 mm by means of round converter it is hard to ensure its abutting and acoustic contact. It is evidently revealed using direct converters for control of crankshafts, rolls and castings with $R_{curv.}$ 80-I00 mm. Sensitivity and reliability of control is higher when using separated-combined converters with rectangular base surface ensuring stability of its position on the surface with $R_{curv.}$ 50 mm and contact liquid on the cellulose base.

THE RESULTS OF INDUSTRIAL ULTRASONIC CONTROL

Determination of HB and σ_B in GC 20 castings of machines gyro cases by US method (equations 5 and 6) on cast surface and industrial tests on castings batches with total amount of 45I pieces. US speed in castings was 3800-4850 mps. In 97 castings (2I.5%) HB and σ_B were less than lower limits of these properties determined by normative-technical documentation. In two castings they were higher than upper limit. Check of 93 control results on 24 castings on Brinell press and tensile-testing machine showed that the tests of US sorting "fit-reject" coincided in full. Divergence of absolute numerical values σ_B determined by US method and by destructive method comprised from 7 to I3 MPa while tests on hardness determined by US method and on the Brinell press comprised from 2 to I7 HB. GC 20 HB and σ_B 45 frames of wood - working machines don't correspond to requirements to the test on 5 castings. Violations of technological process in GC castings bring to formation of chilled layer with high hardness US speed (5600-6000 mps) removed during preparation of surface for control on Brinell press or by portable instruments. In US control on cast surface this layer is taken into consideration. It makes it possible to sort out the castings requiring annealing.

HB was determined for 23I SPHN-50, LPHNd, SShHN-45,48 rolls (equations 7,8,I3). For 90% of rolls divergence of HB values determined by US method and by pressing in the indentor were ≤ 3 HSh. Analysis of measurement results showed that divergence was conditioned by subjective factors during determination of dent diameters, HB change along the length of roll body, surface roughness of samples and rolls in working conditions.

σ_B and $\sigma_{0,2}$ were determined in 24I HC castings of tractor engine crankcases and compared with sample tests on tensile-testing machine. Using US control method (equations II, I2) on cast surface 4 castings (I.7%) were rejected for low σ_B; for sample tests of wedge specimen I4 castings were rejected (6%) including 8 for low and 6 for high σ_B. Satisfactory convergence of results for both methods was obtained on I60 castings (66.4%). For the rest of the castings σ_B divergence was more than ± 30 MPa including difference between σ_B of cast iron in sample and casting. Relation of cast iron properties in wedge sample and casting was determined for II castings. Divergence of σ_B values determined on tensile-testing machine for wedge sample and for casting sample was 0-8I MPa; by US method in casting and sample casting it was 2-46 MPa; by US method in casting and wedge sample it was from -3 to +89 MPa. The biggest similarity of the two methods results was obtained at US control directly in the casting and by tensile test of casting sample - 82%. In another batch of 272 castings 3.7% were rejected for low σ_B using US method; mechanical tests of samples resulted with I7% rejects. Performing control of 300 castings of the third batch by US method only 7 castings were rejected. Low mechanical properties (σ_B = 340 - 440 MPa) correspond to S = 4I80 - 5I30 mps and presence of graphite Gf 2 - Gf I2 in the structure. With S = 5I35 - 5600 mps form of graphite Gf 9 - Gf I3 and mechanical properties correspond to grades HC 45 and HC 50. Controlling σ_B of HC in I30 crankcase castings of another construction it was found out that US speed and σ_B in wedge samples cast with each casting satisfy requirements to this grade of cast iron according to GOST 7293-85. However cast iron directly in the casting by its structure and σ_B corresponds to the HC 40 grade in all six points of US control only in 25 castings (I9.2%). USD of castings (Table I) was realized on cast and preliminarly treated surface.

Table I. USD parameters of castings

Kind of castings	Cast iron grade	R_z mkm	Thickness mm	Working frequency MH_z	Revealed size of defect, mm minimum
Crankshaft	HC 60	20	35... 40	2.5(I.2)	3
Roll	SShHN	300	365	2.5(0.8)	5
Cylinder	GC alloy	400	I2... 46	I.2	5
Hydraulic drive case	CGG	400	I5... 94	2.5(I.2)	3
Crankcase	HC 45	400	20...I20	2.5	4

If cast iron structure in the casting did not correspond to condition of control, lower frequencies were used. Defects of intolerable size, blowholes, draws, slag inclusions, etc. USD results were confirmed by X-ray, destruction and macroexamination of casting cross-section.

Necessity of utilization of US method for complete control of mechanical properties and casting defects and their sorting according to HB and σ_B and destruction methods for taring and confirmation of US test results was ascertained by accomplished research and industrial tests.

REFERENCES

I. Botaky A.A., Ulyanov V.L., Sharko A.V. (I983) Ultrasonic control of construction materials strength properties. Machinostroenie. Moscow.
2. Ivanushkin E.S., Belay G.E. (I982) In: Tenth world conference on non-destructive testings. Volume 5, 2-22, pp. I2I-I28. Moscow.
3. Ivanushkin E.S., Belay G.E. (I984) Ultrasonic control methods in castings production. Tehnika. Kiev.
4. Ivanushkin E.S. (I988) Evaluation of high grade cast iron mechanical properties in castings by ultrasonic method. Liteinoye proizvodstvo, № 8, pp. II-I2.
5. Ivanushkin E.S. (I990) In: Proceedings of the Poster sessions in the 57th World Foundry Congress. D-IO. S. I4I-I44. The Japan Foundrymen Society. Osaka, Japan.
6. Litovka V.L. (I987). Improvement of high grade cast iron quality in castings. Naukova dumka. Kiev.
7. Richter Hans Ulrich, Linke Dieter (I988) Giessereitechnik, 34, № 3, pp. 92-94, № 4, pp. III-I25.