METABK 54(1) 105-108 (2015)
UDC – UDK 621.746:699.163.086.5:620.178.1:620.197.6=111

THE USE OF MATHEMATICAL MODEL OF HARDNESS SPREAD IN THE RESEARCH ON THE PROPERTY OF CAST-IRON MOLDS

Received – Prispjelo: 2014-04-21
Accepted – Prihvaćeno: 2014-09-30
Preliminary Note – Prethodno priopćenje

The paper determines the range and form of a surface layer of a spheroid cast iron founding. It presents proofs of the possibility to form an operative surface of a product in the range of an intermediate surface layer of the cast. Based on research and experience, one has stated that the hardness spread and structures in cross sections of the wall of a cast are the most representative parameters determining the range of the surface layer of the iron cast.

Key words: foundry, cast-iron molds, hardness, surface layer.

INTRODUCTION

Focused on important mechanical and usability features (like the vibration absorption index), spheroid cast iron is one of fundamental cast alloys of iron and carbon among all other moulds and it is widely used in automotive industry, machines industry, casts of pipes and fittings, in glass-making industry and in the production of smelting casts, especially moulds and rolls. Statistics show that the insufficient resistance of surface layer of elements is the major factor causing damage, cracks or even destroying elements of machinery parts. Therefore, one can say with much probability that it is the condition of such surface layer that decides on usability characteristics of these parts [1, 2].

Upgrading the durability and the reliability of parts of machines has become the fundamental task for technology of machine engineering. The implementation of basic theses of this work may be used in practical process of technological product design using spheroid cast iron in the bulk and mass production. In such manufacturing processes, it is worth determining the form and the range of the surface layer in the preliminary mould while preparing preliminary series in order to establish the minimal size of technological surplus. The reduction of surplus for any processing stage brings economical as well as ecological results.

The majority of models accepts *a priori* chosen, i.e. only dominative, phenomena and omits secondary ones, i.e. those which have a smaller affect on a real description of the process. The analysis of characteristics of the surface layer of the SLM (Surface Layer Mould) mould is carried out mostly to prepare methods for constituting the exploitation surface in a way to give it best features and to make costs of product manufacturing the smallest possible. Casts are susceptible to the appearance of defects that might lead to severe damages of the construction while its exploitation. The possibility of forming the determined features, both in the intermediary sphere of the surface and in the initial material, is one of possibilities to significantly affect the quality of molds. Therefore, in order to obtain the highest resistance of materials possible, one can form the determined features both in intermediary sphere of the surface and in the initial material [3, 4, 5]. Therefore, in order to obtain the highest mechanical resistance, especially resistance to stretching – with a relatively high enlargement of the spheroid cast iron, some attempts to form the chosen parameters have been stated: for example the stretch breaking point R_m, minimum limit of flexibility R_{p02}, minimal extending A_5 and hardness HBS [2, 3, 6].

SUBJECT OF THE RESEARCH

All samples have been made from a spheroid cast iron type SGJ 500-7. The cast iron was obtained from an inductive furnace. Temperature of pouring: 1 450 °C. Samples were cast in a circulation molding sand with chemical composition as presented in Table 1. A part of samples, after being molded, was annealed in a resistive furnace. The annealing temperature: 830 °C - graphitizing annealing - eliminating the potential effect of whitening. Time of annealing: 3 h. Time necessary to achieve the temperature of 830 °C: 11 h (heating rate – 75,45 °C/h.). The structure of the cast iron: ferritic and perlitic (15 % of ferrite was an expected value). Time of cooling: 24 h.

The conducted research included above all:

- the study on the hardness spread in cross section with particular attention paid to the surface layer of the mold,

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Table 1 **Chemical composition of a circulation molding sand / %**

Rinsed quartz sand	85 - 89
Special bentonite "S"	8 - 10
Carbon dust	3 - 5
water (humidity)	3 - 3,5
Refreshed mass	2,5 of fresh components

- the study on the hardness spread in the stepped sample,
- the examination of structures in cross section of the wall of the mould with particular attention paid to the surface layer of the cast.

The study was performed on two types of samples of the spheroid cast iron type SGJ 500-7 with chemical composition as presented in Table 2. The examination was conducted on surfaces of samples from the side of the contact with a chill in form of a steel plate with dimensions 120 x 80 x g mm.

The first type referred to samples molded with the chill, not annealed; the second type of sample – characterized with founding with the chill and processed through annealing as an operation enabling further mechanical processing (because it eliminates the effect of whitening). The hardness of samples founded with the chill and unannealed obtained values between 139 ÷ 150 HBS (i.e.76 ÷ 80 HRB). After being founded and cleaned, samples had the grade of roughness of C 20. The roughness in samples processed through machining was Ra = 0,63 μm. The hardness of samples founded with the chill and annealed obtained values between 83 - 100 HBS (i.e. 40 - 52 HRB).

Table 2 **Chemical composition of spheroid cast iron samples used in the examination / %**

Fe	92,8200	Mo	0,0461
C	3,6300	Cr	0,0251
S	2,9900	Cu	0,0243
Mn	0,1930	V	0,0211
Mg	0,0915	Al	0,0200
P	0,0738	Ni	0,0189
Ti	0,0522	S	0,0108

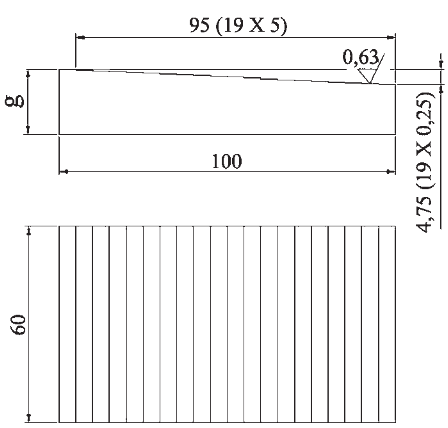

Figure 1 Examination sample of the spread of hardness in one part of the surface layer by means of the step method

Figure 1 shows the stepped sample prepared for the examination of the spread of hardness in cross section of the wall of the mold. Where: g = 10; 20; 30; 40 mm.

EXAMINATION OF HARDNESS

The measurement of hardness was done with the use of a hardness measurement device – type Rockwell, with an indentor in form of a steel bead, in time periods between 3 and 6 seconds, in a way to obtain absolute load. The examination was conducted in accordance with Polish standard (PN-EN ISO 6508-1:2002P). The examination accepted standardized hardness scale B, preliminary load F_0 = 98 N, major load F_1 = 883 N, total load F_c = 980 N, the indentor in form of a steel bead 1/16". The measurement of the hardness was done on surfaces with roughness parameter R_a = 0,63 μm.

Three imprints were made on every established distance from geometrical surface and, in case of the stepped sample, on every step.

The choice of programs for the design of the experiment was based on an preliminary study and literature sources [2, 4, 7 - 10]. Statistical surveys were conducted with the use of programs Statistica and Excel – Analysis Toolpac. The analysis was based on the identification of multi-dimensional objects made by means of the method of regression analysis. The research was conducted with the use of the so-called measurement of the hardness spread in cross section of a wall of a spheroid cast iron founding SGJ 500-7 for annealed and unannealed molds.

Figure 2 shows distributions of hardness for individual samples versus distance from the edge of the wall of the mold.

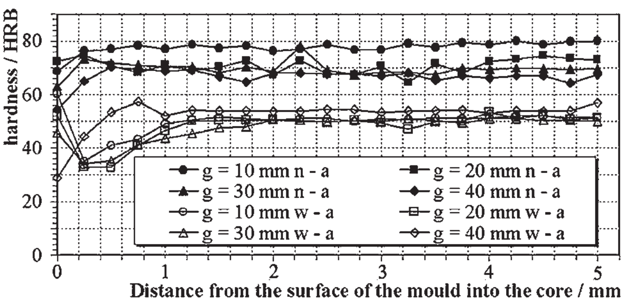

Figure 2 Hardness versus distance from the edge of the mold's wall for a wall of 10; 20; 30; 40 mm and for molds made with the use of a chill (n - a) and for molds made with the use of a chill and annealed (w - a).

Presented graphs (Figure 2) characterize a stability of hardness in the distance from the mold wall circa 0,25 mm for founding made with use of a chill and unannealed; however, in case of molds made with a chill and annealed, the stabilization of hardness took place in the distance of about 1 mm from the wall of the mold.

For the analysis of presented distributions of hardness in cross section of 500 - 7 cast iron molds it is important to notice the following things:

- hardness of the surface of the mold depends on setting conditions and cooling of the form, and it is also as much dependant on the hardness of the sphere of reaction on the surface layer, which constitutes an area, which composition and range depends among others on the predisposition to enter chemical reaction of material of the form with liquid cast iron [1, 3, 6].
- the spread of hardness in cross section of the wall of the cast iron mold depends on cooling abilities applied in the determined molding sand and from the thickness of the wall of the mold,
- the hardness in molds made with use of a chill and annealed is smaller than the hardness in molds made with a chill and unannealed.

STATISTICAL ANALYSIS

When drawing the results of measurements, upper average values were being calculated. However, as the measure of dispersing results around the average value, depending on the number of measurements, a dispersion for $n < 5$ was calculated (the absolute error equals the half of the spread of measurements results), as well as the standard deviation for $n < 5$. For the accepted confidence level $\alpha = 0,05$. Confidence intervals were determined based on *Student's-t-distribution* statistics and distribution tables. Appropriate software was used for the examination too (Statistica 5.0, Excel-Analysis ToolPak, Maple). The importance of the effect of annealing, the thickness of the mold and the distance in the depth from the surface of the founding have been determined on the basis of variance analyses by the assumed materiality level of the *F-distribution* test equal $\alpha = 0,05$.

The following technological parameters were accepted for this analysis:

- heat processing (annealing) as variable x_1,
- thickness of the wall of the mold as variable x_2,
- distance from the surface depth into directions of the core as a variable x_3.

The following mathematical model was accepted (polynomial of the second degree with double interactions):

$$HRB(x_1, x_2, x_3) = b_0 + \sum_{k=1}^{i} b_k x_k + \sum_{k=1}^{i} b_{kk} x_k^2 + \sum_{\substack{k=1 \\ q<k}}^{i} b_{qk} x_q x_k \qquad (1)$$

where b_o - constant of the equation, i – the number of independent variables x for the determined degree, k - the number of the following independent variable.

Based on literature and preliminary research it has been accepted to use multiple regression with non-linear relation for determining the mathematical model of the impact of variables x_1, x_2, x_3 on the hardness. An individual analysis for nonannealed molds and for annealed ones has been conducted. The principal objective of conducted examinations was to find a second type regression equity that would describe the dependency of the hardness on the cross section of spheroid cast iron SGJ 500÷7 molds, starting from the thickness of the founding wall and the distance from the surface of the wall to the depth inside the core of the mold – from the place in which the hardness has been measured.

The following values of examined factors were assumed:

x_1 = 0 or 1,
x_2 = 10; 20; 30; 40,
x_3 = 0; 0,25; 0,50; ...; 20.

Results of conducted analyses are presented in a graphical form in Figure 3.

Four regression equations occurred as a result of the statistical analysis conducted; they describe dependencies of the hardness from the thickness of the wall of the mold and from the distance from the surface to the core of the spheroid cast iron founding (see Figure 3). The regression equations obtained were assessed from the viewpoint of gravity of influences of regression factors and the adequacy of the regression function – using the *F-distribution* test to compare obtained results with its critical value F_{α,r_1,r_2}.

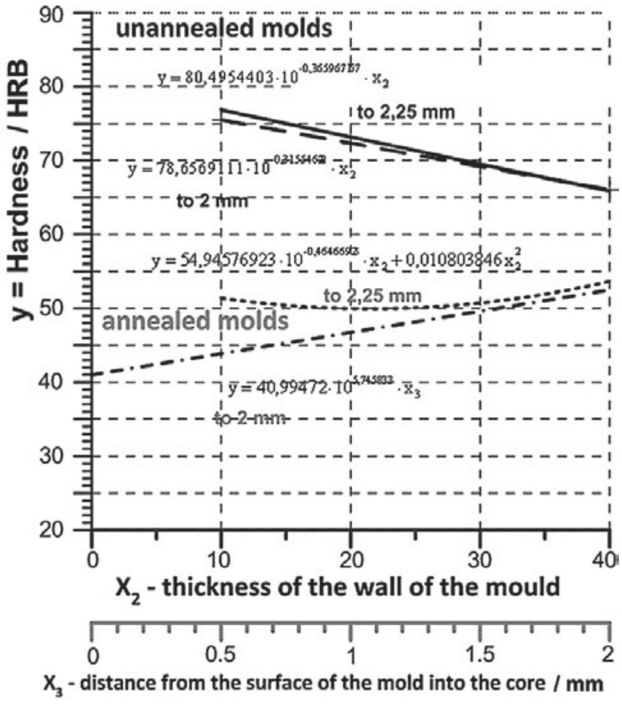

Figure 3 Hardness versus thickness of the wall - x_2 and versus distance from the surface depth into of core - x_3

CONCLUSIONS

Findings of conducted examinations allow us to express the following conclusions:

- There is a possibility of using the intermediate sphere of the surface layer of the mold from spheroid cast iron by shaping in its range the exploitation surface layer of the product and without interfering into the technology.

- There are no explicit premises to practicing big (it is suggested in standards to keep the scale 3,5 ÷ 5 mm) technological surpluses.
- It is advisable and sufficient to use technological surplus of circa 1,5 mm (+ 0,5 mm).
- Reduction of technological surpluses in accordance with the form and range of the surface layer in the spheroid iron cast does not diminish the properties of the surface layer of the final product.

Acknowledgement

This research was supported by grant project VEGA No. 1/0937/12, VEGA No. 1/0102/11 and project FGV/2013/5.

REFERENCES

[1] Kuryło, P., Analysis of the Structure of the Surface Layer of Spheroidal Cast Iron GJS Casts, Procedia Engineering 48 (2012), 320-325.

[2] Kuryło, P., Possibility of Plastic Processing of Spheroidal Cast Iron. Procedia Engineering 48 (2012), 326-331.

[3] Janik S., Wieczorowski K., Wykorzystanie właściwości strefy przejściowej warstwy wierzchniej odlewu żeliwnego dla podwyższenie własności eksploatacyjnych wyrobu, V. Konf. N-T, Politechnika Rzeszowska, Rzeszów, 1995.

[4] Cincio, R.,Selected problems of complex assessment of technical surface topography, Pomiary, Automatyka, Kontrola 56 (2010), 42-43.

[5] Calik, A., S. Karakas, and N. Ucar, Wear behavior of boronised and induction hardened spheroidal graphite cast iron, Journal of the Balkan Tribological Association 18 (2014) 1.

[6] Morino, K., Nishimura, F., Kawagoishi, N., Fatigue Strength of Radical Nitrided Spheroidal Graphite Cast Iron, Key Engineering Materials, 488 (2012), 238-241.

[7] Klonecki W., Statystyka dla inżynierów. PWN, Warszawa-Wrocław 1999.

[8] Buršák, M., Micheľ, J., Influence of the strain rate on the mechanical and technological properties of the steel sheets, Metalurgija. 49 (2010) 4, 317-320.

[9] PN-EN 1563:2012. Odlewnictwo. Żeliwo sferoidalne. Polish standard.

[10] Kinal, G. Paczkowska, M., The comparison of grey cast irons in the aspects of the possibility of Their laser heat treatment. Journal of Research and Applications in Agricultural Engineering 57 (2012)1, 73-76.

Note: English language: Mgr. Ján Želonka, Faculty of Arts, Constantine the Philosopher University in Nitra, Department of Translation Studies, Slovakia