UDK 669.14.018.252:620.17
Professional article/Strokovni članek

ISSN 1580-2949
MTAEC9, 42(1)33(2008)

DEVELOPING AND TESTING A NEW TYPE-8K MOULD FOR TOOL-STEEL INGOT CASTING

RAZVOJ IN PREIZKUS NOVE KOKILE VRSTE 8K ZA ULIVANJE INGOTOV IZ ORODNEGA JEKLA

Martin Balcar[1], Libor Sochor[1], Rudolf Železný[1], Pavel Fila[1], Ludvík Martínek[1], Libor Kraus[2], Dušan Kešner[2], Jiří Bažan[3]

[1]ŽĎAS, a. s., Žďár nad Sázavou, Czech Republic
[2]COMTES FHT, s .r .o. Plzeň, Czech Republic
[3]VŠB TU – Ostrava, Czech Republic
martin.balcar@zdas.cz

Prejem rokopisa – received: 2007-09-26; sprejem za objavo – accepted for publication: 2007-10-15

The traditional production of machinery and tools at ŽĎAS, a. s., and the increasing requirements placed on the final product, particularly those related to the internal quality of forgings, requires new technological measures for the ingot's casting and solidification. The development and use of the new mould type 8K9.2 for tool-steel ingot casting has reduced the share of forgings with unacceptable quality. A substantial improvement has been achieved, especially in terms of the occurrence of defects, such as cavities and cracks in the ingot body.

Keywords: tool steel, mould, ingot casting, solidification, forging, ultrasonic testing

Tradicionalna proizvodnja strojev in orodij v podjetju ŽDAS, a. s., in naraščajoče zahteve pri lastnostih končnega proizvoda, ki so povezane z notranjo kakovostjo izkovkov, so zahtevale nove tehnološke ukrepe pri litju in strjevanju ingotov. Razvoj in uporaba nove kokile vrste 8K9.2 za litje jeklenih ingotov sta zmanjšala delež ingotov nesprejemljive kakovosti. Pomembno izboljšanje je bilo doseženo pri pogostosti napak, razpok in votlin v notranjosti ingota.

Ključne besede: orodno jeklo, kokila, ulivanje ingotov, strjevanje, kovanje, ultrazvočna preiskava

1 INTRODUCTION

The determination of the causes of the internal defects in tool-steel ingots and forgings leads to the implementation of optimisation measures in production technology [1,2]. The requirements for the internal quality of forgings from large blocks, and the conditions for forming in the company ŽĎAS, a. s., represented by the limit of the pressing force, has focused work on the processes of ingot casting and solidification related to ingot-mould shape changes. An optimised form of the ingot 8K9.2 with a mass of 8.9 t, and with a reduced portion of axial defects defined in particular by the Niyama criterion [3] was proposed after a numerical simulation of the casting process and solidification of the forging ingot 8K8.4 with a mass of 7.6 t by applying MAGMA software.

With the use of the new shaped mould 8K9.2 for the casting of tool steel W.Nr. 1.2344 (X40CrMoV51) in ingots with a mass of 8.9 t, the internal quality of the ingots was improved. Ingots with a low share of the poor integrity in the axial part are the basic pre-requisite for the high-quality production of large tool-steel forgings.

2 DEFECTS IN INGOTS MADE OF TOOL STEEL

In the company ŽĎAS, a. s. the production of tools is carried out by processing the 8K ingots with masses of 1000 kg to 11700 kg on CKV 630, CKV 1250 and CKV 1800 presses. In 2006 the forming force for the CKV 1800 press was increased from 18 MN to the current value of 22.5 MN.

The traditional assortment of tool steels consists of, e.g., the steel grades **90MnCrV8**, X37CrMoV51**,** **X40CrMoV51**, 55NiCrMoV7, X210Cr12 and special steels for the rolls in rolling mills: 8CrMoV, **8Cr3MoSiV**, 8CrMoSiV.

When producing forgings from tool steel, the problems are connected with the low plastic properties related to the high content of carbon in combination with the content of the alloying elements, chromium, molybdenum and vanadium. Sufficient forging through the ingot and the elimination of internal defects, particularly in the zone of the end of solidification, in the axial part of the ingot, requires a high degree of forming and a sufficient deformation volume.

In the case of large forgings with a diameter that make it impossible to achieve the necessary deformation in the axial part of the ingot by forging, the required internal quality is obtained with an improvement of the ingot's internal quality.

3 VERIFICATION OF THE INGOT 8K9.2

The design of the new mould shape is based on an analysis of numerous modifications to the mould geometry ensuing from the existing polygonal ingot of the type 8K8.4 with a mass of 7600 kg.

The main changes to the geometry were made from the viewpoint of slenderness and the bevel of the ingot body. The final shape was, afterwards, adapted and verified with modelling of the ingot 8K9.2 with a mass of 8850 kg. A comparison of the basic parameters of the ingot 8K8.4 and the design of the new shape of the ingot 8K9.2 are given in **Table 1**.

Table 1: Basic parameters of the ingot 8K8.4 and the design of the ingot 8K9.2
Tabela 1: Osnovni parametri ingota 8k8.4 in načrt ingota 8K9.2

Type	Mass and volume					*S* slen-derness	*V* taper
	ingot	head		body		$\frac{H}{D}$	°
	kg	kg	%	kg	%		
8K8.4	7 600	800	11%	6 800	89%	2.1	4.8
8K9.2	8 850	1 200	14%	7 650	86%	1.3	11.0

The steel **X40CrMoV51** was chosen for the verification of the quality of the ingots and the forgings. Two heats were cast into two ingots, 8K8.4 and 8K9.2, each. One ingot from the heat was always submitted for analyses of the chemical composition from the viewpoint of segregations and structural heterogeneities, while the second ingot was processed by forming on the CKV 1800 press to produce a bar with a diameter of 350 mm with the maximum use of material, i.e., without the technological waste associated with the technology of open-die forging.

3.1 Chemical heterogeneity of the ingot

For a comparison of the chemical heterogeneity of the ingots made from the steel grade **X40CrMoV51** the chemical composition of the ingots of the types 8K8.4 and 8K9.2 was determined on a cross-section in the longitudinal direction according to the layout shown in **Figure 1**. The results of these analyses were compared to the results of heat analyses, and on the basis of the differences, positive and negative values of the absolute differences of the individual elements were determined.

The diagrams in **Figure 2** and **Figure 3** show the positions of the greatest differences in the carbon concentration, i.e., in the axis along the height of the ingot of types 8K8.4 or 8K9.2. **Figure 4** shows the changes in the concentration of sulphur in the axis along the height of the ingot of type 8K8.4 and then along the height of the ingot of type 8K9.2.

Figure 6 and **Figure 7** show the deviations of the molybdenum concentration from the heat analysis in the axis along the height of the ingot type 8K8.4 or 8K9.2.

From the absolute deviations of the elements determined from the samples of steel taken during the casting of ingots it is obvious that with the solidification of steel in the mould 8K9.2 a more distinct segregation of carbon, sulphur and molybdenum occurs along the ingot axis in comparison to the mould 8K8.4.

In **Figure 8** it is possible to compare the differences in the segregation of elements at the surface, at a distance of ½ of the radius from the surface (middle radius), and in the axis of the ingot 8K9.2. The higher content of carbon at the ingot surface is probably related to the used casting powder, which contains the mass fraction of C up to 21 %. At the place marked as ½ of the radius (middle radius) and also in the ingot axis, at the foot part the carbon is being negatively segregated and at the top part a positive segregation occurs, whereas the

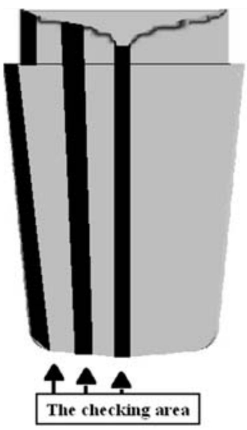

Figure 1: Layout of samples for analyses of the chemical composition
Slika 1: Položaj izreza vzorcev za kemijsko analizo

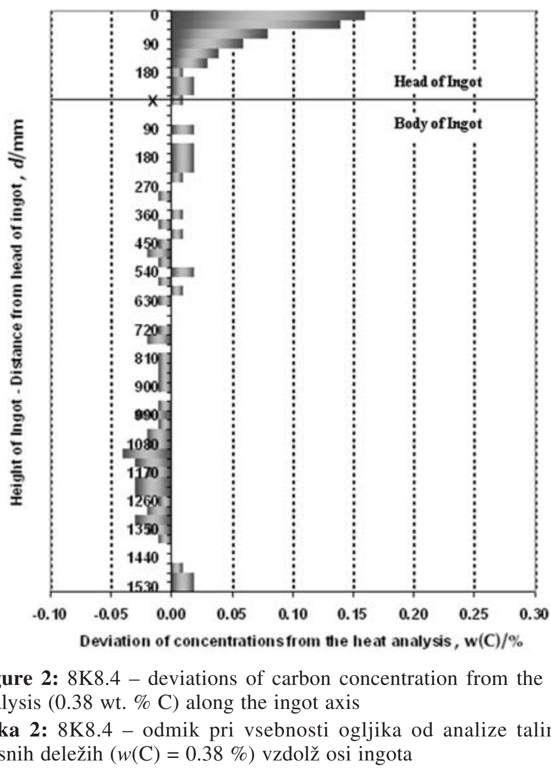

Figure 2: 8K8.4 – deviations of carbon concentration from the heat analysis (0.38 wt. % C) along the ingot axis
Slika 2: 8K8.4 – odmik pri vsebnosti ogljika od analize taline v masnih deležih (w(C) = 0.38 %) vzdolž osi ingota

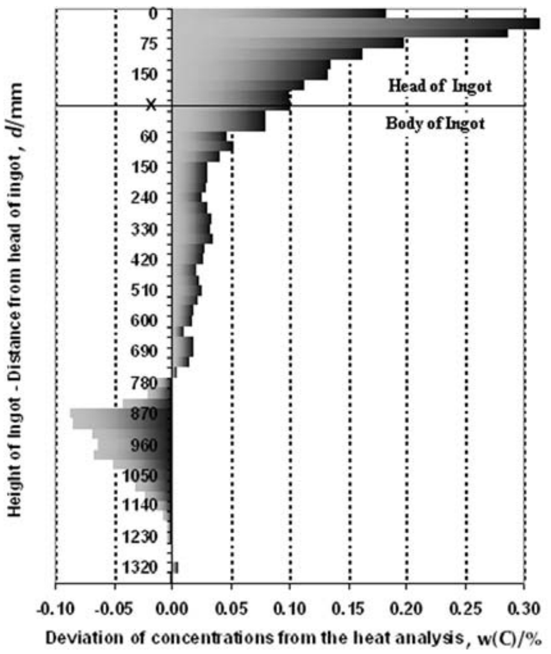

Figure 3: 8K9.2 – deviations of carbon concentration from the heat analysis (0.38 wt. % C) along the ingot axis

Slika 3: 8K9.2 – odmik pri vsebnosti ogljika od analize taline v masnih deležih (w(C) = 0.38 %) vzdolž osi ingota

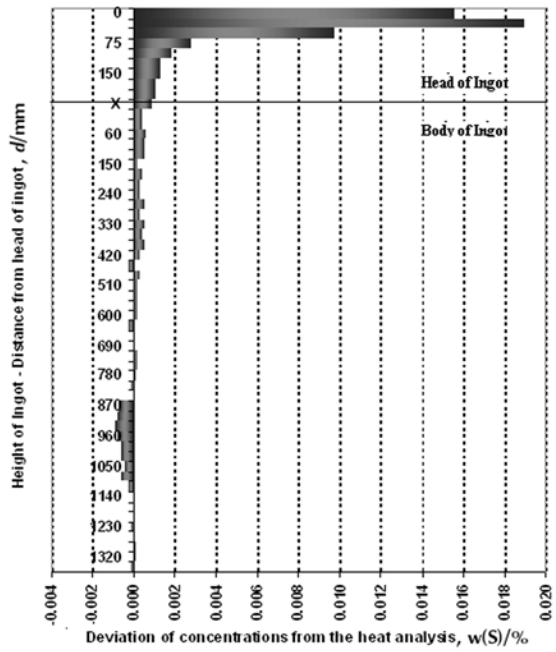

Figure 5: 8K9.2 – deviations of sulphur concentration from the heat analysis (0.0035 wt. % S) along the ingot axis

Slika 5: 8K9.2 – odmik pri vsebnosti žvepla od analize taline v masnih deležih (w(S) = 0.0035 %) vzdolž osi ingota

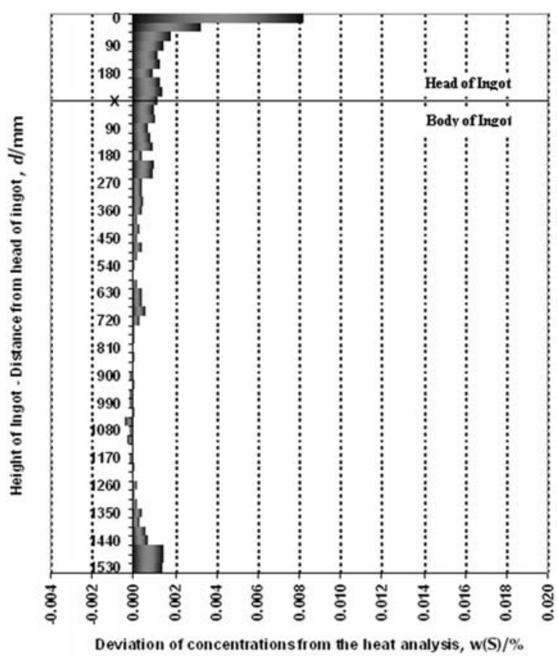

Figure 4: 8K8.4 – deviations of sulphur concentration from the heat analysis (0.0060 wt. % S) along the ingot axis

Slika 4: 8K8.4 – odmik pri vsebnosti žvepla od analize taline v masnih deležih (w(S) = 0.006 %) vzdolž osi ingota

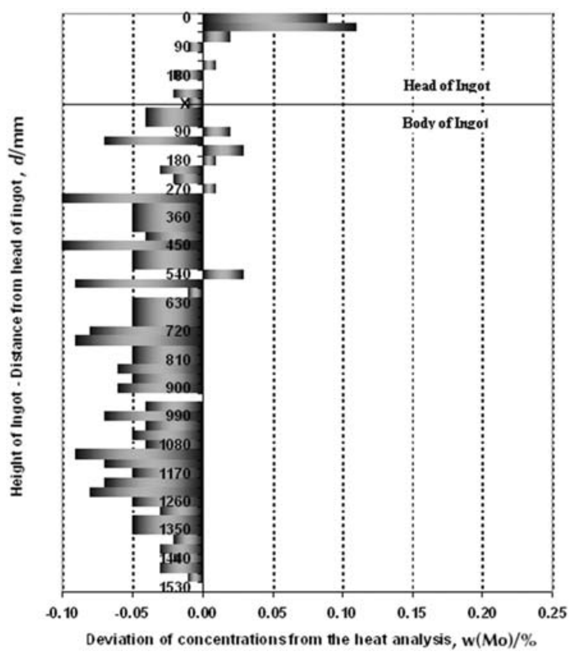

Figure 6: 8K8.4 – deviations of the molybdenum concentration from the heat analysis (1.25 wt. % Mo) along the ingot axis

Slika 6: 8K8.4 – odmik pri vsebnosti molibdena od analize taline v masnih deležih (w(Mo) = 1.25 %) vzdolž osi ingota

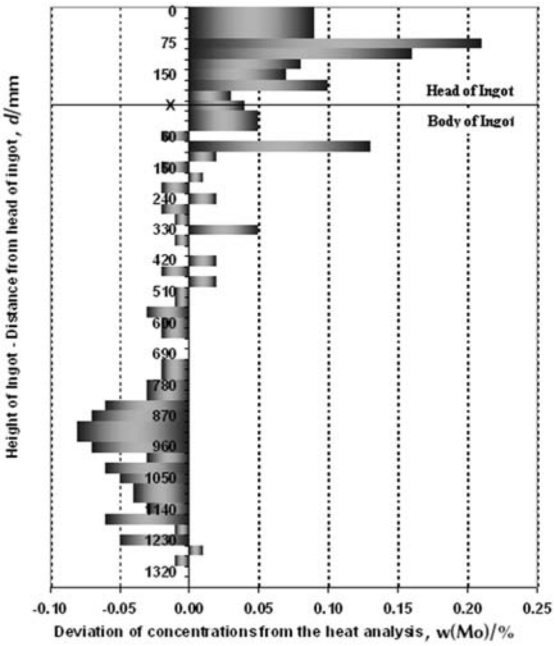

Figure 7: 8K9.2 – deviations of the molybdenum concentration from the heat analysis (1.25 wt. % Mo) along the ingot axis

Slika 7: 8K9.2 odmik pri vsebnosti molibdena od analize taline v masnih deležih (w(Mo) = 1.25 %) vzdolž osi ingota

axial part of the ingot is characterised by greater differences in the concentrations.

It is possible to verify the results of the numerical simulation using the MAGMA software with a comparison of the curve in **Figure 8** with the curve in **Figure 9**. It is evident that in real conditions more distinct differences occur from the viewpoint of the absolute change of the carbon concentration. The numerical simulation also does not take into account the possibility of carburisation of the melt by carbon pick up from external sources. The contribution of the numerical simulation is apparent in the area of the determination of

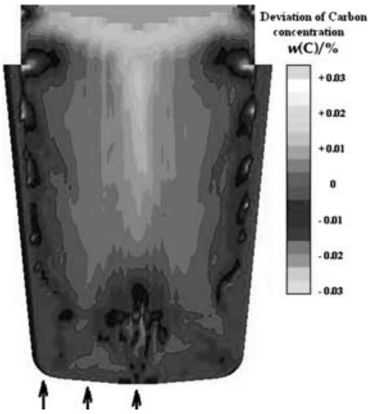

Figure 9: 8K9.2 – MAGMA deviations of carbon concentrations along the height of the ingot body

Slika 9: 8K9.2 – MAGMA odmik pri vsebnosti ogljika po višini ingota

the distribution of positive and negative segregations on the ingot's cross-section.

3.2 Structural defects of ingots

Real forgings were investigated for a practical verification of the spread of internal defects. The following ingots were cast from the steel X40CrMoV51:

- ingot 8K8.4 – **bottom casting**
- ingot 8K8.4 – **top casting**
- ingot 8K9.2 – **bottom casting**

After cutting the ingots and completing a capillary test by wet testing, the pictures that were taken were changed to a graphical transformation with the aim to accentuate the ingot defects. The obtained appearance of an internal part of the ingot in cross-section is shown in **Figure 10 to Figure 12**.

The pictures confirm the influence of the casting technology and the shape of the mould on the spread of internal defects. A more detailed investigation of the size

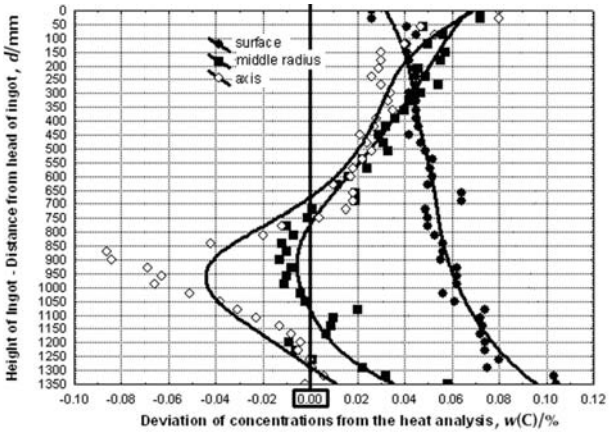

Figure 8: 8K9.2 – deviations of carbon concentration from the heat analysis (0.38 weight % C) along the height of the ingot body

Slika 8: 8K9.2 – odmik pri vsebnosti ogljika od analize taline v masnih deležih (w(C) = 0.38 %) po višini ingota

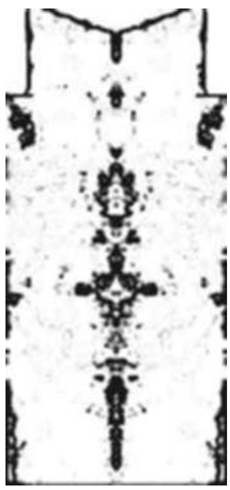

Figure 10: 8K8.4 bottom cast ingot – ingot defects

Slika 10: 8K8.4 ingot ulit od spodaj – napake v ingotu

Figure 11: 8K8.4 top cast ingot – ingot defects
Slika 11: 8K8.4 ingot ulit od zgora – napake v ingotu

Figure 12: 8K9.2 bottom cast ingot – ingot defects
Slika 12: 8k9.2 ingot ulit od spodaj – napake v ingotu

of individual defects shows that the ingot 8K9.2 contains cracks that are 1 mm wide and with a length up to 10 mm, while the ingot 8K8.4 contains along the ingot axis – regardless of the casting technology – continuous cracks and voids with widths above 5 mm and lengths up to several centimetres, in some cases.

3.3 Results of ultrasonically testing the forging

The main part of the evaluation of the influence of changes of the mould shape on the production of forgings made from tool steels were tests of the internal quality of forgings with ultrasonics in accordance with the standard **SEP 1921**. The verification of the quality of the experimental forging from the ingot 8K9.2 of steel **X40CrMoV51** was performed according to the degrees A/a, B/b, C/c, D/d, E/e, with the level ***D/d*** or possibly ***E/e*,** considered as acceptable for the given steel.

On the basis of measurements and from the comparison of the results of the statistical evaluation of the previous production of forgings from the steel grade X40CrMoV51, summarised in **Table 2**, it is evident that a change in the mould shape brought a significant increase in the utilisation of the ingot, as well as an enhancement of the forging's internal quality.

Table 2: Utilisation of ingots of steel X40CrMoV51 – ultrasonic testing according to the SEP 1921
Tabela 2: Uporaba ingotov iz jekla x40CrMoV51 – ultrazvočna kontrola po SEP 1921

Type	Mass kg	Guaranteed US	Ingot utilisation kg	Ingot utilisation %
8K8.4	7600	B/b	5950	78%
		C/c	5450	72%
		D/d	4600	61%
		E/e	0	0%
8K9.2	8850	E/e	7300	82%

The test bar forged from the ingot 8K9.2 satisfied the requirements of all the degrees of ultrasonic tests and the length of the bar corresponded to 82 % of the utilisation of the ingot's volume. The remaining material in the forging could not be used due to cracks in the ingot's head and footing crop end due to material flow and the necessity of aligning the forging's front face with machine cutting.

The optimistic conclusions based on an investigation of one forging were confirmed by the results obtained on real forgings of bars and blocks from tool steels with a mass up to 7 t and a bar diameter up to 600 mm, or the height of a block up to 500 mm.

4 CONCLUSIONS

The verification of the results of a numerical simulation with examinations on real ingots confirms the influence of changes of the mould geometry on the segregation in the ingot. The degree of chemical heterogeneity of the ingot also depends a great deal on the type of cast steel.

The change of the casting technology did not decrease the quantity of defects, such as cracks and voids, along the axial part of the ingot to an acceptable level. Important changes in the distribution and shape of the internal defects of the ingot were noted in ingots cast into the new shapes of the moulds of the type 8K9.2.

On the basis of the results of the investigation it was possible to obtain a substantial enhancement of the internal quality of the forgings with a simultaneous reduction in the share of unsatisfactory forgings that did not pass the ultrasonic testing, as a consequence of the change in geometry of the forging ingot of the type 8K9.2 with a mass of 8.9 t.

The investigations were performed within the TANDEM program of the FT_TA/061 project. The project was funded partially with the financial support of the Ministry of Industry and Trade of the Czech Republic.

5 LITERATURE

[1] Martínek, L., Balcar, M., Novák, J., Sochor, L.: Analysis of internal non-integrities of the ingot made of tool steel, 6th International metallurgical symposium, Rájecké Teplice, 2003

[2] Martínek, L., Balcar, M., Novák, J., Sochor, L.: Internal structure of the ingot made of tool steel, 20th conference Theory and practice of making and processing of steel, Rožnov, Tanger, 2003

[3] Carlson, K. D., Shouzhu OU, Hardin, R., Beckerman, CH.: Development of new feeding – distance rules using casting simulation: Part I. Methodology.

[4] http://www.engineering.uiowa.edu/čbecker/documents.dir/FeedingPart1.pdf