DEVELOPMENT OF NEW TYPES OF TOOL STEELS DESIGNED FOR FORGING DIES

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Tool steels used for forging dies are mostly made from medium and high alloyed steels. In terms of their use at forging these steel grades are divided to grades for hammer dies and steel grades for forging press dies. In case of grades for hammer dies high toughness is required above all and alloying conception depends on it (mostly based on nickel with chromium, molybdenum and possibly vanadium). In case of forging press dies the spectrum of the available properties is wider and individual steel grades are more dissimilar from each other according to usage of specific type of die or forging. Basically in these cases of dies an optimal combination of hot strength, toughness, resistance to tempering and other properties are required. This article presents new alloying conceptions of steel grades for dies concerning the grade 1.2343, which are produced in the company ŽĎAS, a.s. By modification of chemical composition and by corresponding metallurgical processing followed by special forging process very good combination of hardness toughness and abrasion resistance was reached. Dies are tested in production conditions in the forging plant Kovárna VIVA a.s. and the lifetime is on average approx. by 50 – 100% higher then that of the standard tool steel grade X38CrMoV5–1, (W.Nr. 1.2343).

Keywords
tool steel, die forging, hardness and abrasion resistance, resistance to wear.

1. Introduction

Manufacturers of small die forgings take a considerable long interest in affordably priced tool steels with a good strength-to-toughness ratio and with the accurately defined method of metallurgical processing. Such steels find their relatively general-purpose application in most types of dies.

The representative typical of such a tool material is the steel X38CrMoV5–1 (W.Nr. 1.2343, per DIN 17350/80), thereinafter called as steel 1.2343, which is the most widely used in European forging plants. However, it is often difficult to find on the Czech market the supplier of this type of steel who would guarantee not only required chemical composition but also homogenous microstructure and high micropurity, uniform distribution of carbides and other parameters being decisive for the end-use properties of dies.

During last years, the companies ZDAS, a. s. and Vítkovice – Vyzkum a vyvoj – technické aplikace, a. s. have intensively occupied oneselves, in cooperation with the forging plant Kovárna VIVA, a. s. and with research institutes SVUM, a. s. and COMTES FHT, a. s., by the problems of optimization of the manufacture of steel 1.2343 so that the best properties can be achieved while maintaining a competitive price. In addition to the development of the metallurgical processing technology for this steel, there were also made several suggestions for modifications of chemical composition. The modifications are suitable especially for manufacture of dies with high requirements in respect of hardness and abrasion resistance.

2. Experimental steelmaking

2.1 Quality requirements

Based on long-term requirements of tool-steel buyers, the following basic quality requirements have been established in respect of final forged semi-products made from tool steels:

- maximum sulfur content 0.005 wt.%, minimum content of phosphorus and other undesirable accompanying elements
- content of nonmetallic inclusions (as per ASTM E45-97) not exceeding the values given in Table 1
- size of the original austenitic grain G = 8 or finer (as per ASTM E 112)

INCLUSIONS		
TYPE	THIN	HEAVY
A (sulfides)	1.0	0.5
B (aluminates)	1.5	1.0
C (silicates)	1.0	1.0
D (glob. oxides)	2.0	1.0

Table 1. *Maximum content of nonmetallic inclusions in the tool steel*

In addition to these basic criteria, the steels tested were evaluated in respect of micro-segregation as per NADCA 207, distribution of carbides and other standard microstructure parameters.

2.2 Manufacturing process

Experimental ingots were processed in a vacuum (VD technology). Before the process of forging, one ingot was arc remelted using VAR equipment. The above quality requirements were satisfied also in the case of material produced using VD technology without remelting. As expected, vacuum arc remelting has resulted in the improvement of quality parameters (zero content of inclusions). However, owing to high costs of this type of technology and the unavailability of VAR equipment within the company ZDAS the use of remelted ingots has been abandoned.

To achieve optimum forming, all below mentioned materials were, after having been cast, forged in three axes (i.e. spreading in combination with upsetting) with forging reduction of at least 4.

3. Modification of chemical composition of the steel 1.2343

With respect to specific parameters of the test die used for testing of tool steels (see chapter 5), there were made several suggestions for the modifications of chemical composition (see Table 2), which result above all in the improvement of hardness and abrasion resistance.

Compared to standard composition of the steel 1.2343, the modification 1 was finish-alloyed using niobium whose effects on carbon formation are often utilized both in structural steels [Pereloma 1999] and tool steels. [Dobrzanski 1997] [Novak 2005]

In the case of modification 2, the carbon content was increased to reach even higher hardness and hardenability, in addition to finish alloying using niobium and vanadium.

In the case of modification 3, compared to the steel 1.2343, the carbon content was also increased and moreover the steel was finish alloyed using tungsten and vanadium.

4. Experimental steel property analyses

The samples from experimental heats were heat treated to reach the values of hardness 53 HRC (all samples), 55 and 57 HRC (only for samples with modified chemical composition). Then the impact strength tests in the longitudinal and perpendicular directions

Steel grade	Chemical composition (wt. %)							
	C	Si	Cr	Mn	Mo	V	Nb	W
1.2343 * standard	0.37	1.00	5.00	0.40	1.20	0.45	–	–
Modification 1 (Nb)	0.39	1.00	4.95	0.40	1.16	0.42	0.18	–
Modification 2 (Nb, C)	0.54	1.00	4.95	0.40	1.15	0.62	0.18	–
Modification 3 (W, V, C)	0.49	1.00	4.90	0.40	1.17	1.60	–	1.63

** grade X38CrMoV5–1, (ČSN 41 9552)*

Table 2. *Chemical composition of tested tool steel modifications*

Steel grade	Hardness HRC	Toughness KCU [J/cm²]		Wear resistance ψ*
		∥	⊥	
1.2343 standard	53	23	20	1.69
Modification 1 (Nb)	53	23	16	1.83
	55	16	11	1.93
	57	12	7	2.06
Modification 2 (Nb, C)	53	20	15	1.85
	55	15	11	1.95
	57	11	7	2.08
Modification 3 (W, C)	53	21	15	1.82
	55	15	10	1.89
	57	11	6	2.00

** resistance to wear ψ is the ratio of the etalon volume abrasion to the volume abrasion of the material being tested*

Table 3. *Mechanical properties of samples from experimental materials (measurements taken at 20 °C)*

(towards the axis, bars forged from the original ingot) and abrasion resistance tests have been carried out.

The results of tests carried out are shown in Table 3. It follows from these results that the modifications of chemical composition have led to a considerable increase of hardenability (the hardness over 53 HRC is not attainable in case of standard steel 1.2343) and to the improvement of wear resistance. In case of all modifications it has also been, however, found that there was a decrease of impact strength, above all in the direction perpendicular to the axis of a semi-product being forged. To eliminate this effect, the ingot reforging technology continues to be further optimized.

In addition to mechanical tests, the evaluation of microstructure was performed according to the specification included in Chapter 2.1. As regards the monitored criteria, all experimental materials were evaluated as satisfactory. A minimum content of inclusions was reached and the size of the original austenitic grain was within the limits G = 8–10 in case of all samples tested.

An example of the microstructure of standard steel 1.2343 produced by the company ZDAS and visible boundaries of the original austenitic grain are shown in Figure 1.

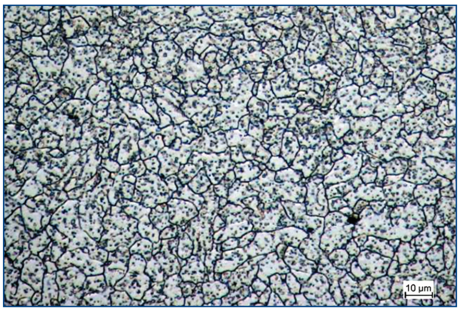

Figure 1. *Example of microstructure 1.2343 produced by ZDAS, a. s. with visible boundary of original austenitic grain (G = 8)*

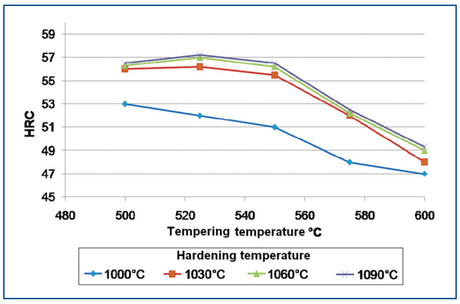

Figure 2. *Tempering curves – modification 1*

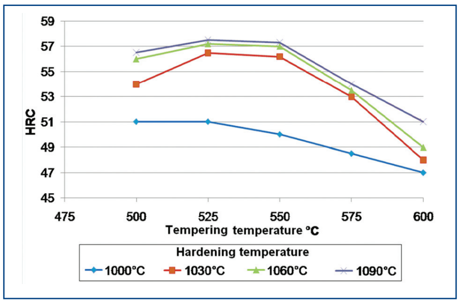

Figure 3. *Tempering curves – modification 2*

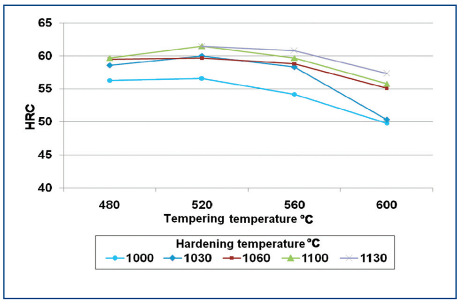

Figure 4. *Tempering curves – modification 3*

In case of steels with modified chemical composition the tempering curves shown in Figures 2 through 4 were also measured.

5. Forging die tests

The forging die shown in Figure 5 is used in the forging plant Kovárna VIVA a.s. for forging of small die forgings (about 1kg in weight). In view of great lots of manufacture (as many as 100 000 forgings per year for a period of several years) this die was evaluated as very suitable for tests of new tool materials.

Before the commencement of tests, the die was made from standard steel 1.2343 heat-treated to 47 HRC and its lifetime was 4 304 strokes. It follows from the character of wear (see Fig. 5 below) that, during operation, above all, abrasion wear and local plastic deformation of the die occur, but without its cracking. For this reason a suggestion was made that the die material should be heat-treated to have higher hardness.

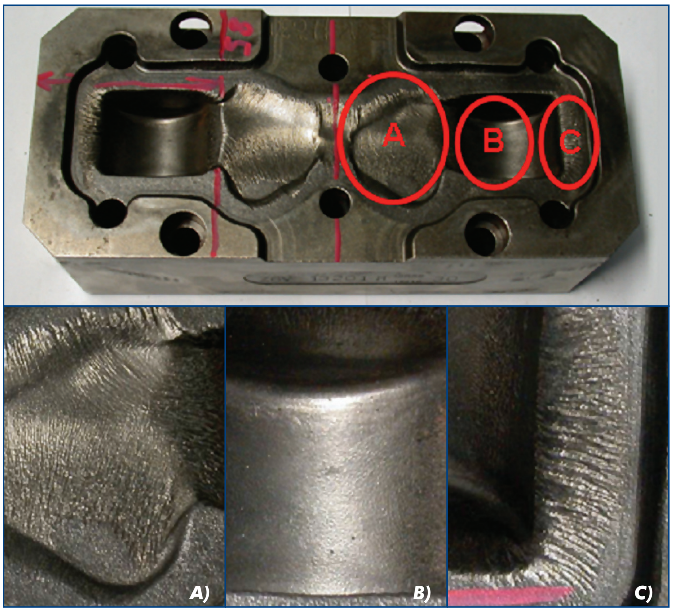

Figure 5. *Experimental forging die (dimensions 275 x 120 x 78 mm) and character of wear*

Steel grade	Direction of forging grains to dividing plane of die	HRC	Lifetime (number of strokes)
1.2343	Across	47	4 304
1.2343	Across	53	7 080
1.2343	Lengthwise	53	7 628
Modific. 1 (Nb)	Across	54	8 499
Modific. 2 (Nb+C)	Across	54	9 388
Modific. 3 (W+V+C)	Across	54	8 470
Modific. 3 (W+V+C)	Lengthwise	56	7 759

Table 4. *Review of selected results of tests of dies made from steels concerned*

A series of tests have been carried out in case of dies made from the typical steel 1.2343 and from the above described modified materials heat-treated to 50 HRC using a standard method. During testing, the technological forging conditions were found to be stable and the lifetime of dies was monitored. The results of selected tests are stated in Table 4. It appears from these results, that higher hardness lead to a considerable improvement of the lifetime of the die (about by 70%) even without the modification of chemical composition of the tool steel. The use of the steel with modified chemical composition has resulted in even higher lifetime of the die at the same hardness – the lifetime was improved by up to 100% compared to the original condition.

All tested modifications of chemical composition have proven in practice and can be considered suitable for the manufacture of forging dies.

6. Conclusions

It follows from the above results that the success came in the development of technology for manufacturing the high-quality tool steel suitable for hot work and having chemical composition corresponding to the designation acc. to W. Nr. 1.2343.

Furthermore, the test semi-products made from steel with three various modifications of chemical composition were produced, thus ensuring above all a higher hardenability and abrasion resistance. All the materials under examination have been practically tested on the forging die at the forging plant Kovarna VIVA a.s. The use of such materials has resulted in a better lifetime of this die.

The tests carried out in the forging plant have showed, among other things, that, in some cases, the dies can be heat-treated to hardness which considerably exceeds the value of 50 HRC, without cracking during operation. In view of the positive results of carried out tests, it is possible to consider all tested modifications of steel 1.2343 as practically suitable tool materials for hot working. Since 2009, the above-described modifications have been protected by utility models.

References

[Dobrzanski 1997] Dobrzanski, L. A.; Zarychta, A.; Ligarski M.: High-speed steels with addition of niobium or titanium, *Journal of materials processing technology,* vol. 63, Issues 1–3, January 1997, pp. 531-541, ISSN 0924-0136

[Fila 2010a] Fila, P., Balcar, M., Martinek, L., Suchmann, P., Krejcik, J., Jelen, L., Psik, E., Development of new types of tool steels designed for forging dies.. *Kovárenství*, September 2010, No.38, pp.11–14. ISSN 1213-9289 MK CR E15370

[Fila 2010b] Fila, P., Balcar, M., Martinek, L., Suchmann, P., Krejcik, J., Jelen, L., Psik, E., Development of new types of tool steels designed for forging dies. *Proceedings of the 10^{th} international symposium FORM 2010,* Brno, 14. – 15. 9. 2010

[Novak 2005] Novak, P.; Vojtech, D.; Serak J.: Pulsed-plasma nitriding of a niobium–alloyed PM tool steel, Materials Science and Engineering A, February 2005, vol. 393, Issues 1–2, pp. 286–293

[Pereloma 1999] Pereloma, E. V.; Timokhina, I. B.; Hodgson, P. D.: Transformation behaviour in thermo-mechanically processed C-Mn-Si TRIP steels with and without Nb, Materials Science and Engineering A, December 1999, vol. 273 – 275, pp. 448 – 452

[Suchmann 2010] Suchmann, P., Krejcik, J., Fila, P., Jelen, L., Psík, E., Development of new tool steels for forging dies. *Proceedings of the conference Metal 2010*, Roznov pod Radhostem, 18. – 20. 5. 2010, ISBN 978-80-87294–15-4

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