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Development of a New Tool Material for High Pressure Die Casting

A. Herman*, P. Zikmund, F. Tatíček
Department of Manufacturing Technology, Faculty of Mechanical Engineering, Czech Technical University in Prague, Technická 4, 16607 Prague 6, Czech Republic
*Corresponding author. E-mail address: ales.herman@fs.cvut.cz

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Abstract

The paper describes existing requirements for tool materials. In the light of experience with these supplied materials, we have demonstrated their considerable influence on the life of molds for die casting technology. From this research came the evaluation methodology of these tool materials which has been used for directing the development of a new material. Based on the new regulation of the chemical composition a sample was casted and forged after that. Then was determined the process of heat treatment and from a block of this material a mold insert was produced. This insert is now being tested in production.

Keywords: Innovative foundry technologies and materials, Metallography, Die material for HPDC technology, Wear resistant alloys

1. Introduction

Evaluation of tool materials is relatively complicated thing. The trend of the past 20 years is the use of the NADCA methodology. It is based on testing the supplied material (thermally unprocessed and after heat treatment). This test does not take place directly on finished form, but on the test rods obtained from the supplied blank part. The aim is to identify the source of any problems that may occur either directly in the production of semi-finished product (supplier), or subsequently after the heat treatment of finished mold by the manufacturer (customer). Test results may show some differences in properties compared with the real mold. These differences may be caused during manufacturing process in relation to the dimensions of the test sample and tool inserts (e.g. during thermal processing may be different cooling rates).

The base method used according to NADCA is testing of impact toughness - problem is the high dispersion of values obtained by measurement and the fact that these values can be significantly influenced by the human factor.

Principle of this method shows that impact testing using Charpy hammer opens possible cracks. Test at room temperature can get quite a few different values. If we would chose a pressure test, there would be a closing of cracks, variance of values would be minimized, but there were no adequate disclosure of other possible faults.

Another aspect is the hardness of the material. NADCA recommends the use of the method according to Rockwell. However, this method does not have a sufficiently high sensitivity, but it has long been used. Higher sensitivity and precision reaches Vickers method.

Years of experience have shown that it is necessary to follow a low content of hydrogen, oxygen and nitrogen in the base material. These elements may cause undesired fragility. Other undesirable elements are Sn and Zn - low-melting metals, whose source is especially scrap recycling metallurgy. These elements can be eliminated by feedstock purity and particularly by special melting processes (vacuum melting and vacuum remelting or electro slag melting and remelting).

Unfortunately, from our previous research, we confirmed that despite modern methods of melting and remelting supplied alloys contain relatively large amounts of low-melting metals (e.g. to 0,5 - 0,7% Zn) which increase the propensity for die cracking. There is no information on the exact chemical composition in the material list – you can find only spread of values. Spectral analysis is typically done on a single melting and continuously casted semi finished product has homogeneous properties. Content of alloying elements quite often varied more than tenths of a percentage - e.g. provision was 0.5% and in fact 0.75% V, or 5.2% Cr and 4.6% Cr in fact. forging to this partly eliminated ... In the case of vanadium, where difference was up to 50%, it is even dangerous – vanadium significantly increases susceptibility to high-temperature temper brittleness.

Therefore, a new certified methodology for tool materials was assessed (Certificate 6577 LL-C Certification [1]), which is already used in the tool shop ŠKODA Auto Mladá Boleslav and Kovolis Hedvikov Inc.

2. Thesis of the same methodology

A specimen will be removed from the supplied block of material measuring 20x20x20mm to perform spectral analysis, metallographic grinding and hardness testing. Here, suppose the block in the state after annealing, i.e. without performing additional heat treatment.

For subsequent analysis after further processing is required to process the sample simultaneously with a block of material or remove new, preferably from nonfunctional side (corner) of the mold insert or core.

2.1. Chemical analysis

Supplied materials must comply with the range of chemical composition in the following table with regard to the material sheet according to the supplier.

Table 1.
Regulation of the chemical composition of the most widely used tool materials

Chemical composition	C		Si		Mn		P		S		Cr		Mo		V	
	min	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**
TQ1	0,33	0,4	0,1	0,5	0,3	0,5		0,02		0,002	5	5,5	1,7	2	0,5	0,7
Dievar	0,32	0,38	0,1	0,5	0,4	0,55		0,02		0,002	4,8	5,3	2,2	2,5	0,5	0,7
W403	0,37	0,42	0,1	0,5	0,15	0,3		0,02		0,003	5	5,5	2,75	3,05	0,6	0,8
Thyrotherm	0,33	0,43	0,8	1,2	0,2	0,5		0,015		0,002	4,75	5,5	1,1	1,6	0,3	0,6

The sample must not contain low-melting metals, in particular Sn, Zn, Pb - especially considering that these elements form a low temperature melted eutectics with significantly increased risk of die cracking. With regard to the production method (electro slag or vacuum remelting) must not be presented also other elements (the recommended maximal content of other elements not included in the table above may be 0.1%)

Testing is performed as follows: at least 3 spectrometric sparks are performed on specimen and their evaluation, there are compared with the defined ranges of chemical composition according tab. 1., and then compared with suppliers certificate (particularly with regard to the possible occurrence of elements not listed in the protocol). The conclusion is that the material meets or does not meet terms of chemical composition.

2.2. Metallography

Metallographic analysis is recommended in the delivered state and after heat treatment, specifically in all its stages (i.e. after hardening and three times tempering).

Delivered condition - evaluated: the presence of inclusions according to ISO 4967 (all groups must meet the criteria of max. 0.5), the presence of segregation (evaluated metallographic pattern in 50x magnification, must not contain segregation belts). Furthermore, the excretion of carbides, which may adversely affect the die life (evaluation – magnification 500x - 1000x). Inadmissible are:

- Clusters of carbides
- Uneven distribution of carbides
- Carbides in clusters at grain boundaries
- Oxidation of borders - corrosion at grain boundaries

And the last the size and direction of grains is evaluated. It is necessary to know the position and orientation of the sample in the original block of material, for reverse determination of the direction of grains. On the basis of the detected direction suitably select a block of material orientation during machining with respect to the yield distribution in the finished form. The evaluation is made according to DIN EN ISO 643.

From the delivered condition leads to the conclusion that the material meets or does not meet the above criteria (inclusions, segregation, poor orientation, or uneven distribution of carbides).

After heat treatment (HT) is evaluated from a metallographical specimen:

1. The quantity of retained austenite (max. 10-20%)
2. The size of martensite laths (max. 20μm)
3. The presence of carbides - see the delivery condition

After evaluating that the material complies or is not suitable from the viewpoint of HT.

2.3. Hardness

Hardness (HRC) is detected on the sample for the delivered state and after every stage of heat treatment, i.e. after quenching and tempering. We are recommended method Rockwell (HRC) and Vickers. The results compare with hardening respectively. Tempering curve of the material to be verified the correct execution of the heat treatment. Tolerances of tests ± 1 HRC, ± 10 HV. After evaluating the material meets or does not meet the terms of HT, and hardness corresponds or not.

And the main problem with this method? If you have 40HRC and you change by 1 HRC, then the difference is 11HV. But if we do the same thing to 50HRC, then the difference is 14 HV. If we do this to 60HRC, the difference is 24HV and 43HV for 70HRC. The material will have a hardness of processing state, so the normalized condition is OK but in the hardened state it is a problem. So we suggesting to be stopped using the HRC and require the use of HV.

2.4. Evaluation of the heat treatment process

Here it is necessary to have a protocol from HT, which terminates on whether they were following the correct hardening and tempering processes. Especially it is necessary to avoid region of high-temperature brittleness, which has been demonstrated for these materials in the range of 540-590 ° C.

Similarly, it is necessary to evaluate the protocol on tempering temperatures. From these curves it is necessary to do the first tempering in the formation of temper brittleness (irreversible creation of vanadium carbide), similarly to the second tempering, which should be done by ca 30 ° C above the first tempering temperature must avoid this critical area. After evaluation will be determine whether heat-treated material was satisfactory or unsatisfactory in terms of formation of temper brittleness.

3. Designing new material

To the draft of the new material leads us the attitude of suppliers of materials that everything is already proven, tested, incl. production process. So we decided to look at new material from the beginning (with respect to the preparation of a utility model we are not going to describe details of chemical composition, only the working title HPDC New Steel - further HPDCNS). The main theses of our proposal is based on the purity of the feed (absent the low-melting metals), the material is lower in the content, from the viewpoint of reducing the risk of high temperature embrittlement is partially increased content of other alloying elements and carbon, replacing the excluded vanadium carbides. In compliance with the contents of S and P less than 0.02%

The batch was designed and prepared as follows (all were checked by the spectrometer Q4 TASMAN the presence of undesirable elements):

- Deep-drawing first sheet without zinc: 0.16% C, 0.27% Si, 0.32% Mn, 0.06% Cr, 0.010% Mo, 0.003% V, 0.01% P and 0.01% S, rest Fe
- 2. Steel C16E: 0.15% C, 0.29% Si, 0.74% Mn, 0.04% Cr, 0.003% V, 0.01% P and 0.015% S, remainder Fe
- Third ferrovanadium FeV80: 0.3% C, 1.27% Si, 78% V, 0.04% P and 0.06% S, remainder Fe
- Fourth Ferromolybdenum FeMo: 0.1% C, 1.2% Si, 68% Mo, 0.04% P and 0.08% S, remainder Fe
- Low carbon ferrochrome fifth FeCr LC: 0.1% C, 1.2% Si, 60% Cr, 0.02% P and 0.03% S, remainder Fe

On the basis of the draft of final composition were determined individual shares of the charge.

4. Selecting the type of tool inserts for die casting

Insert for testing newly proposed material was chosen so that the volume was meltable in furnace and gave him normally handled during forging (cca 60 kg). Insert was selected, which is ¼ of die insert (number 65552). This insert is used for regular production of large doses of castings with regard to the construction of a mold where four inserts are applied, so we can also test other materials at the same time.

Dimensions of the device: 240x250x50 mm. As blank casting we selected prism with dimensions of 270x260x125 mm. The selected volume is chosen with regard to the required large forging value of inserts, when we wanted to achieve significant grain refinement.

5. Experiment

The feed material was melted in an electric induction furnace under protective atmosphere of Ar. Casted to open furan mold. Casting temperature was 1600 ° C.

After casting the structure was evaluated as coarse-grained as seen in FIGS. 1 and 2, dendrite structure (casting was heat treated with a view to the next forging process) with sorbitol structure. With closer look individual needles sorbitol, bainite and martensite can be seen. In Figs. 5 and 6 can be seen a color spectrum of the individual components in the material.

The material can be considered as satisfactory (material criteria)- inclusions do not occur here, the material is homogeneous, there are no segregations, martensite lath size ranges from 10 to 80 microns - this corresponds to the grain size ca 80 to 120 microns.

This material was subsequently forged. Forging temperatures ranged from 1150 ° - 950 ° C. Before forging, the casting was annealed for 10 hours at 1150 ° C (furnace temperature 1180 °). Forging was carried out on a hydraulic press CBJ500 (see Fig. 7).

After forging, the material was reheated to upper forging temperature (for 3 hours) and forged again. There were twelve of these cycles in order to get homogenous structure. After every four forging cycles insert was annealed (temperature 1150 ° C - 4 hours), followed by cooling in the furnace to ambient temperature. In each cycle was removed part of the material for metallographic tests.

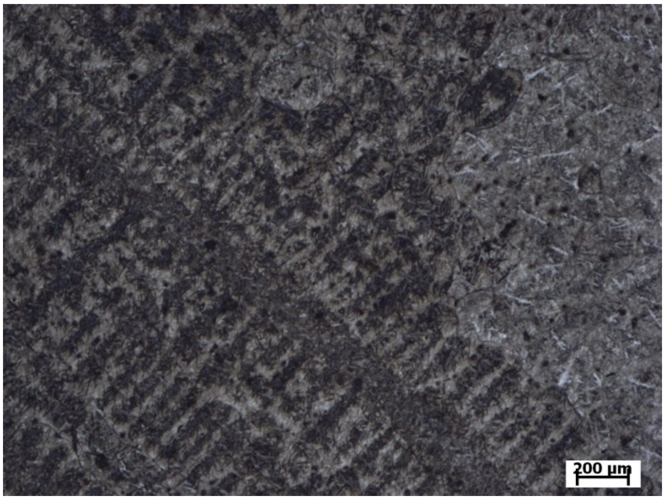

Fig. 1. Structure cast HPDCNS material at 25x magnification

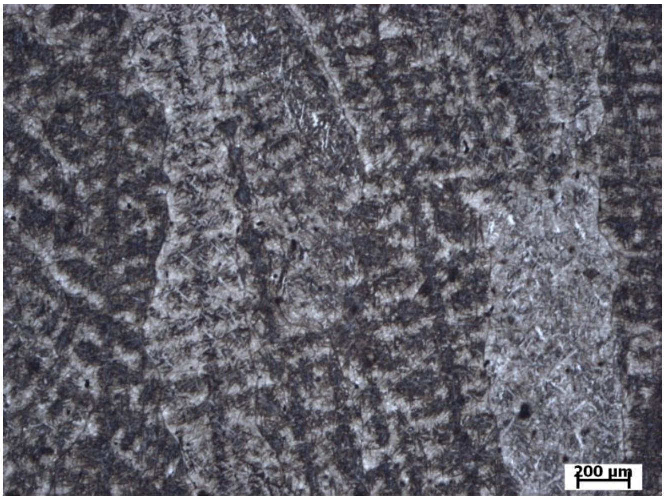

Fig. 2. Structure cast HPDCNS material at 25x magnification

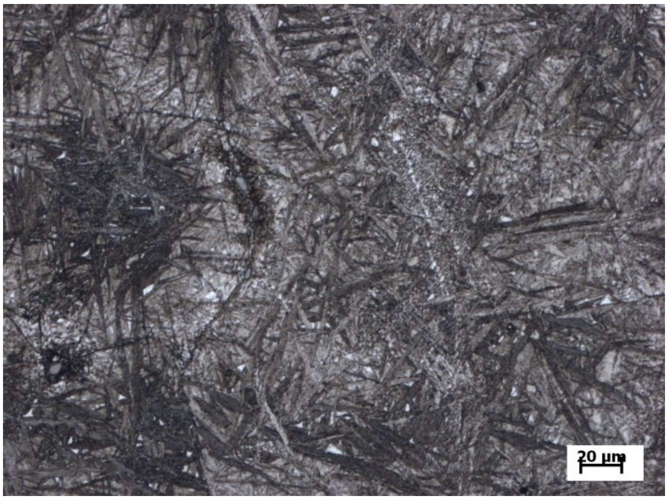

Fig. 3. Structure cast HPDCNS material at 200x magnification

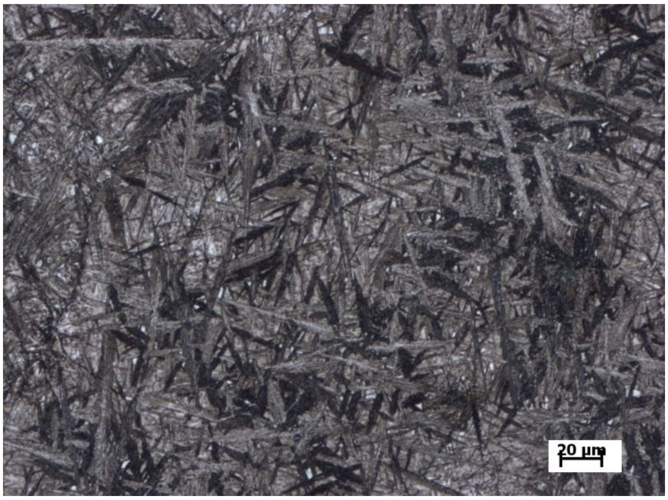

Fig. 4. Structure cast HPDCNS material at a magnification of 200x

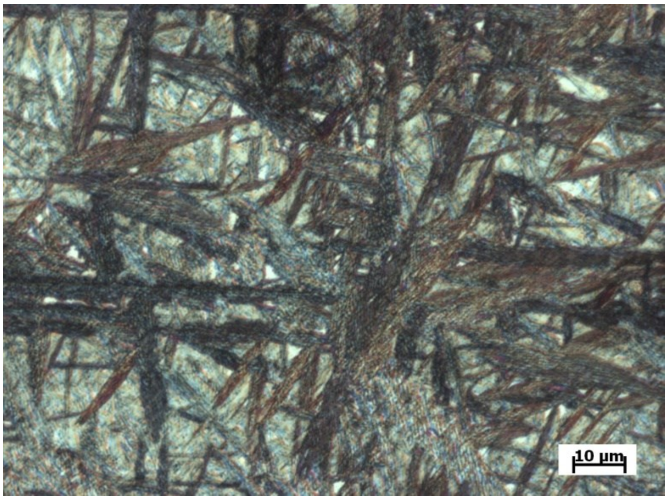

Fig. 5. Structure HPDCNS cast material at 500x magnification DIC

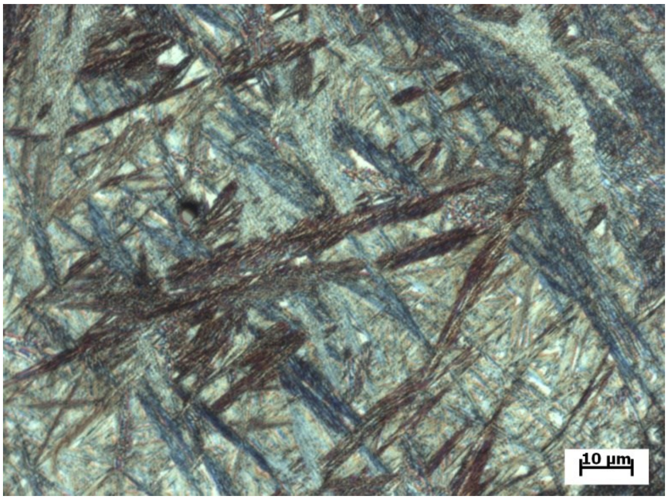

Fig. 6. Structure HPDCNS cast material at 500x magnification DIC

After the first cycle (i.e. four forging operations) material was homogeneous without segregation. The average grain size is between 70 to 80 um (see Fig. 8 and 9).

Fig. 7. Forging inserts

After another 4 cycles forged structure is already substantially finer and the average grain size ranges between 40 to 50 micron, in the structure is visible even good distribution of carbides (Fig. 11).

After the last four cycles, when the blank was forged to 65 mm thickness, is seen the finest structure. The grain size ranges from 30 to 40 microns. The structure of the material is homogeneous (see FIGS. 12 and 13).

After the forging, the material was annealed at 1150 ° C for 8 hours and there was a gradual cooling in the furnace. This material was machined to desired insert, which was then treated by quenching and tempering.

The recommended procedure was heating to 1000 ° C, oil quenching, tempering to a hardness of HRC 48 - first tempering 590 ° C, the second tempering 620 ° C, the third tempering 600 ° C.

After heat treatment, the insert was regrinded and polished to the final shape and since August 2014, it is used in production.

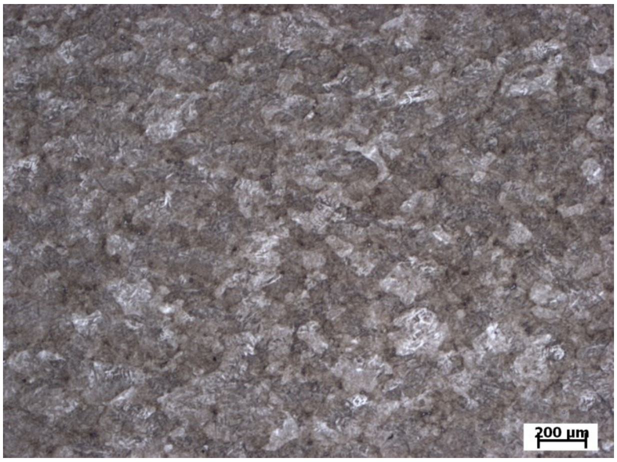

Fig. 8. Structure HPDCNS material after 1st round of forging at 20x magnification

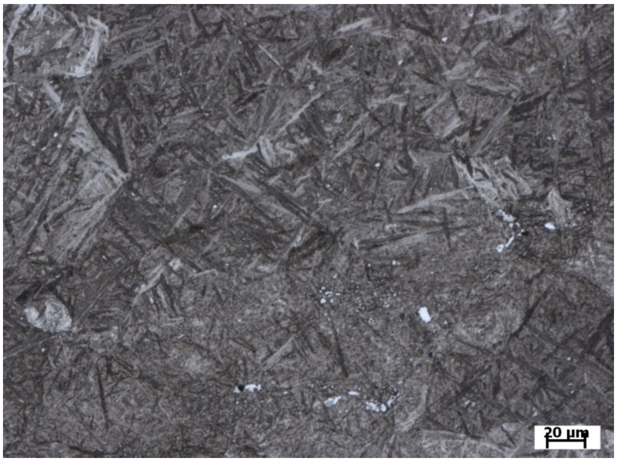

Fig. 9. Structure HPDCNS material after 1st round of forging at a magnification of 200x

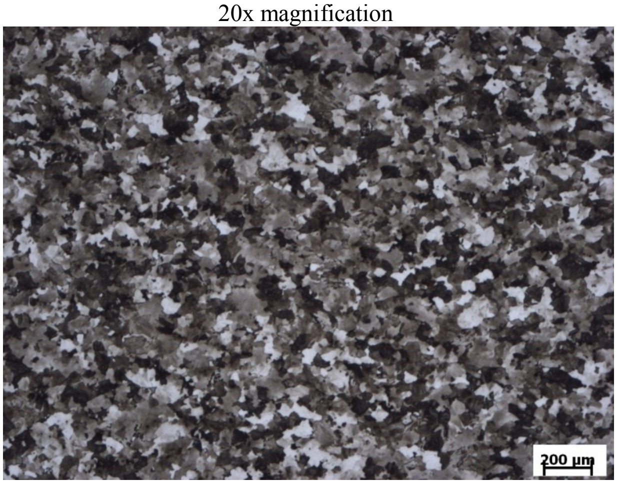

Fig. 10. Structure HPDCNS material after 2 cycles of forging at 20x magnification

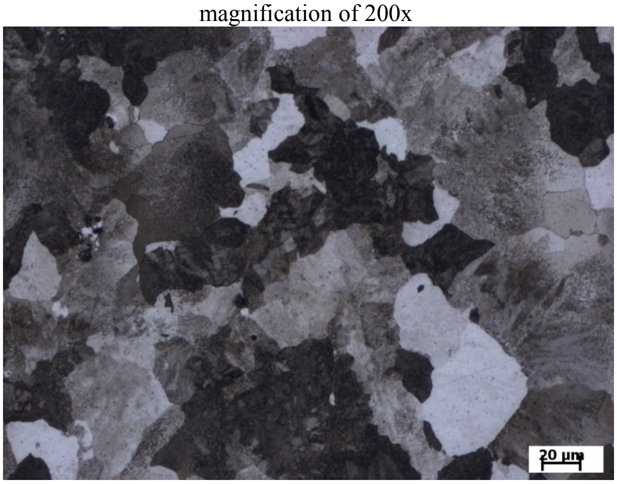

Fig. 11. Structure HPDCNS material after 2 cycles of forging at a magnification of 200x

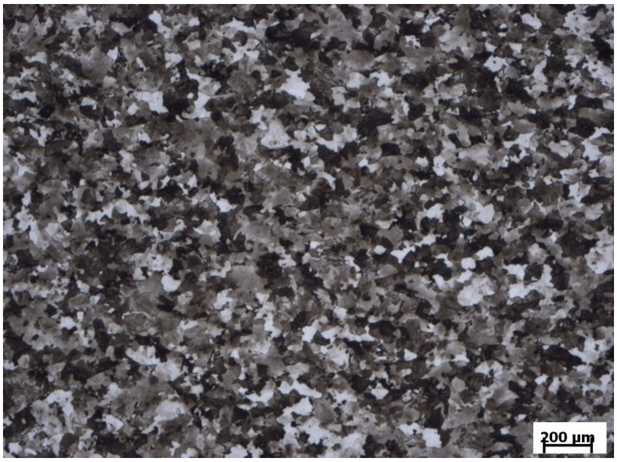

Fig. 12. Structure HPDCNS material after 2 cycles forging at 20x magnification

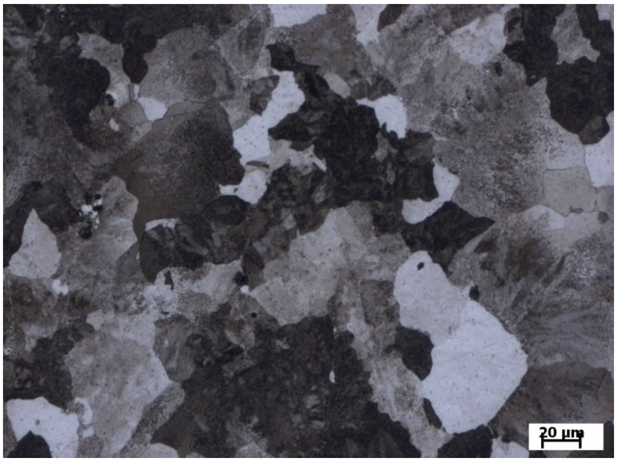

Fig. 13. Structure HPDCNS material after 2 cycles forging at a magnification of 200x

6. Conclusions

The paper describes the problems of tool materials used for inserts for die casting. The article describes a new method use for the evaluation of materials used to manufacture these inserts. Also described is a newly designed material and technique for its preparation. Tool insert was verified in production in tool for pressure casting.

There were also other inserts placed in the die from DIEVAR, W403 and TQ 1. This method was used to compare the lifespan of individual proposed materials. This die went through cca 120 thousand casting cycles till now. This is already beyond normal life of die that is roughly between 60 to 80 thousand cycles. Other materials were selected according to the above method and found to be satisfactory as well. Meanwhile, the first signs of wear and tear on the material showed DIEVAR, starring microcracking (it was repaired with welding and polishing). Other inserts have yet no signs of damage.

It is now observed that the newly designed material which is processed into lower hardness has the same lifetime as the other materials, which are also selected according to our certified methods. In order to minimize the occurrence of impurities in our material, we expect that life of insert will be min. about 20-40% larger than for other insert materials in the die. This should substantiate our hypothesis that also low content of undesirable elements affects the die life. If this material will be successful in other tests, the legal protection of this material will be made and we will offer details. Even at this moment it is the interest of the two largest Czech pressure foundries to deliver the material from which they can expect better life, not material where there is a crack forming after a few hundred cycles.

Acknowledgments

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