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SUITABILITY OF TECHNICAL MATERIALS FOR MACHINERY SUBSOILERS FOR SOIL TILLAGE

Radek Bednář, Jiří Votava, Jan Červinka, Martin Fajman

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Abstract

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Agricultural soil processing belongs to the basic elements in the process of crop production. Currently classic tillage method is decreasing and the only trend has stated as a shallow plowing. Suitable post harvest soil tillage greatly affects yields in the next cycle. The aim of the study is the analysis of abrasive wear of selected construction materials and their subsequent use for DXRV-HD cultivator. The performed tests are focused on monitoring the mechanical properties of the materials and their use for variable cutting tip of cultivator body. Tested materials are divided into four categories. These materials include tool steel (19436), carbon steel (12050), cast iron with globular graphite and welding material supplied as a functional complex on low carbon steel by the Abraweld company.
These materials are tested together with the original part of share cultivator. The present experiment is focused on metallorgraphic, mechanical and abrasive analysis. Structural component of the material is identified by metallographic photos and then compared with the impact strength tested on Charpy hammer. Followed the abrasion resistance according to CSN 01 5084 and the total evaluation of the tested samples are done.

abrasive wear, construction material, laboratory test

Postharvest processing of agricultural land is an irreplaceable part of the cycle of crop production. This operation demands very much energy and the connection between the cultivation and soil fertility are need to realize. Compacted and often devastated land is not longer able to provide sufficient nutrients for crop, even though all the available chemicals were used to start the growing cycle. The abrasive wear has a dominant position in the field of tillage. This abrasive wear is characterized by the separation of the material particles from the surface of the functional component (Blašković *et al.,* 1990). The main cause of high tool wear for soil preparation are SiO_2 particles. Their hardness reaches up to 1280 HV. Heat treatment of steel has a total effect on the wear. Hardened carbon steel has approximately double resistance to abrasive wear on the abrasive cloth than the steel left in its natural state (Suchanek *et al.,* 2007). Soil processing machines begin to use the castings produced of ADI cast iron for simplicity of manufacture of interchangeable parts. The lack of this material is reduced strength after heat treatment. These materials are suitable for the soil conditions with decreasing proportion of the soil skeleton (Votava *et al.,* 2007). Another known method of reducing costs for replaceable parts for soil preparation is suitably selected welding system. The main aspect of this technology is the location of the weld and its dimensional proposition. Inappropriate weld is declared in rapid increase of fuel consumption. On the contrary, properly selected welding system can 2–3× times prolong the life of the component without increasing energy intensity (Vysočanská *et al.,* 2012).

MATERIALS AND METHODS

The test according to CSN 01 5084 was chosen to compare the abrasive wear of materials. This is the test for abrasive cloth. The selected materials can be divided into 4 categories:

- Structural steel of 12 050 and 19 416
- ADI Nodular cast iron (GJS 700-2)
- Carbide weld (CDP Bars)
- Original material used for cultivator (Gregoire Besson producer).

Characterization and thermal processing test materials:

19 436 (X210Cr12) steel: is a high-alloy steel with suitable hardenability and high abrasive resistance. This steel is used mainly in the production of cutting tools for materials with improved abrasion (Řasa, 2007). Chemical composition and heat treatment of this material is shown in Tab. I and Tab. II.

12 050 (C45E) steel: This material is mainly used for highly stressed machine components and dynamically loaded elements. This steel has good toughness after appropriate heat treatment. Chemical composition and heat treatment of this material are shown in Tab. III and Tab. IV.

ADI nodular cast iron GJS 700-2: This material is suitable for casting wall thickness of 5–75 mm. This nodular cast iron is used for highly mechanically and dynamically loaded components. This material is resistant to abrasive and erosive wear (Skočovský *et al.*, 2005). Chemical composition and heat treatment of this material is shown in Tab. V and Tab. VI.

CDP bars: The weld is made with a high content of unidirectionally arranged carbide tips on soft sheet of steel grade 11 that provide high areal abrasion resistance. These plates are in chromium-nickel matrix. This material is characterized by high resistance to abrasion and suitable toughness due to a combination weld on a soft surface.

RESULTS AND DISCUSSION

Macrohardness measurement

The resulting hardness of the steel components has a considerable predicative ability of its life and general wear (Dillinger, 2007). Toughness and material ability to absorb impacts in contact with soil fractions (skeleton) are highly important in the point of view of soil processing. Hardness measurements were performed on five samples using HRC method as shown in Tab. VII. Chemical

I: *Chemical composition of 19436 steel*

Identification according to ČSN EN 10027-2	Chemical composition [%]									Points of conversion [°C]			
	C	Mn	Si	Cr	Mo	V	W	Ni	Ost.	Ac_1	Ac_3	Ar_1	Ar_3
19 436	1.8	0.5	0.5	12	-	-	-	-	-	800	830	740	720

II: *Heat treatment of 19436 steel*

Samples	Quenching			Tempering	
	Austenitizing [°C]	Dwell [°C]	Cooling medium	Warming [°C]	Cooling medium
Sample 1	950	20	oil	300	air
Sample 2	950	20	oil	600	air

III: *Chemical composition of 12050 steel*

Identification according to ČSN EN 10027-2	Chemical composition [%]									Points of conversion [°C]			
	C	Mn	Si	Cr	Mo	V	W	Ni	Ost.	Ac_1	Ac_3	Ar_1	Ar_3
12 050	0.42	0.5	0.17	0.25	-	-	-	0.30	-	720	780	725	785

IV: *Heat treatment of 12050 steel*

Samples	Quenching			Tempering	
	Austenitizing [°C]	Dwell [°C]	Cooling medium	Warming [°C]	Cooling medium
Sample 1	800	20	oil	300	air

V: *Chemical composition of steel ADI cast iron*

Identification according to ČSN EN 10027-2	Chemical composition [%]								
	C	Mn	Si	P	S	Cu	Al	Mg	Ca
GJS 700-2 42 2307	3.48	0.08	2.37	0.03	0.006	0.72	0.013	0.039	0.02

VI: *Heat treatment of cast iron ADI*

Samples	Quenching			Tempering	
	Austenitizing [°C]	Dwell [°C]	Medium	Warming [°C]	Medium
Sample 1	880	20	Salt bath	300	Salt bath

composition and heat treatment of the material have significant effect on hardness as it is evident from the resulting average.

Impact test in bend ČSN EN 10045-1

The utility of the material properties in the impact stress are determined using impact test in bend. The results correlate with the behavior of the tested material in terms of resistance to brittle failure (Pohoda, 2005). The samples were made according to the dimensions specified in the ČSN EN 10045-1 standard. The tests were performed on the test equipment (Charpy hammer). 5 samples of each test material were produced for the experiment. The arithmetic average was calculated for each measurement as shown in Tab. VIII. CDP material was not tested because of the diversity of the underlying material.

The fracture surface of 19436 steel positively shows signs of crystalline fracture as shown in Fig. 1–2. A considerable number of differently oriented bright facets points trancrystalic cleavage of basic metal material.

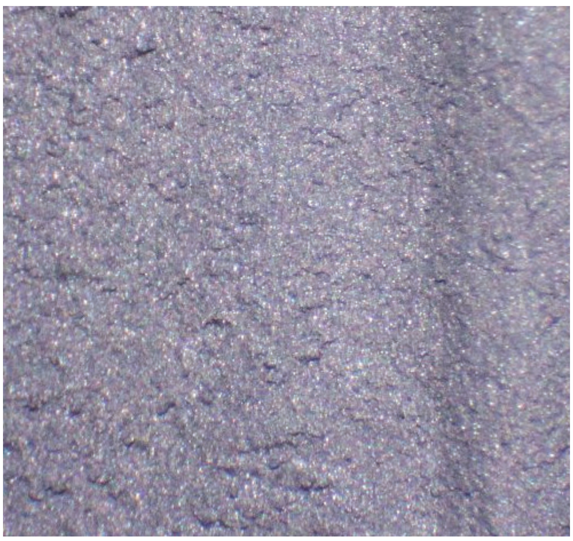
The fracture surface of heat treated 12050 steel is formed in the middle of crystalline fracture on the Fig. 3, which gradually turns into a fracture surface of tough character. The amount of bright facets also points to the fragile violation of the middle part. The

VII: *Hardness of materials used*

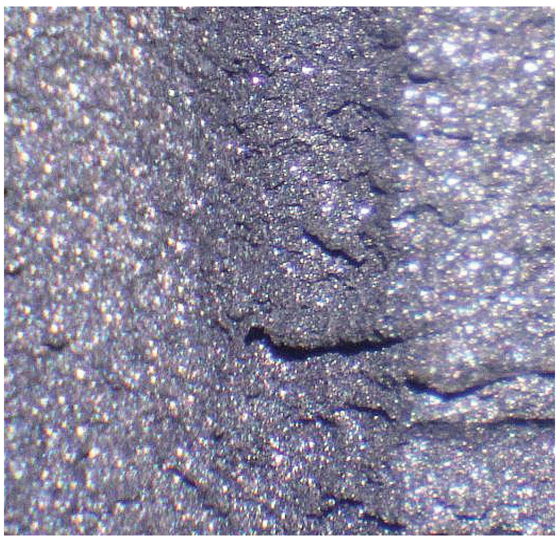
Used steel	Numbers of measurement					Average [HRC]
	1 [HRC]	2 [HRC]	3 [HRC]	4 [HRC]	5. [HRC]	
19436 tempered 300 °C	53	54	54	53	53	**53.4**
19436 tempered 600 °C	46	46	47	46	46	**43.2**
12050 tempered 300 °C	34	35	35	34	35	**34.6**
ADI cas iron	32	32	33	32	33	**32.4**
CDP bars (carbide)	62	63	63	61	61	**62.0**
Original material	45	45	44	45	45	**44.8**

VIII: *Values for impact toughness in used samples*

Used steel	Numbers of measurement					Average [J/mm²]
	1 [J/mm²]	2 [J/mm²]	3 [J/mm²]	4 [J/mm²]	5. [J/mm²]	
19436 tempered 300°C	0.4	0.4	0.4	0.4	0.4	**0.40**
19436 tempered 600°C	0.7	0.7	0.6	0.7	0.7	**0.68**
12050 tempered 300°C	3.3	3.4	3.3	3.3	3.2	**3.30**
ADI cast iron	3.7	4.1	3.8	3.5	4.2	**3.86**
CDP bars (carbide)	can not be tested by this method					
Original material	4.0	4.1	4.0	4.0	4.0	**4.02**



1: *Fracture surface of 19436 steel tempered 300 °C*



2: *Fracture surface of 19 436 steel tempered 600 °C* fracture surface of ADI cast iron can be described as matte tough fracture as seen from Fig.4, which is caused by the exclusion of carbon in the form of graphite.

Test equipment with abrasive cloth

The test on abrasive cloth was chosen to test the resistance to abrasive wear. This test is normalized according to ČSN 01 5084. The test machine with abrasive cloth Fig. 5 consists of a uniformly rotating horizontal plate (1) on which is mounted abrasive cloth (2). The specimen (3) is held pulling head (4) and is pushed against the abrasive clothe force of weight (5). Furthermore, the device consists of (6) allowing radial displacement of the sample and limit switch (7). The test piece is moved from the center to the edge of abrasive cloth during the test. The parts of its surface constantly comes into contact with the abrasive cloth.

Technical data of the equipment:

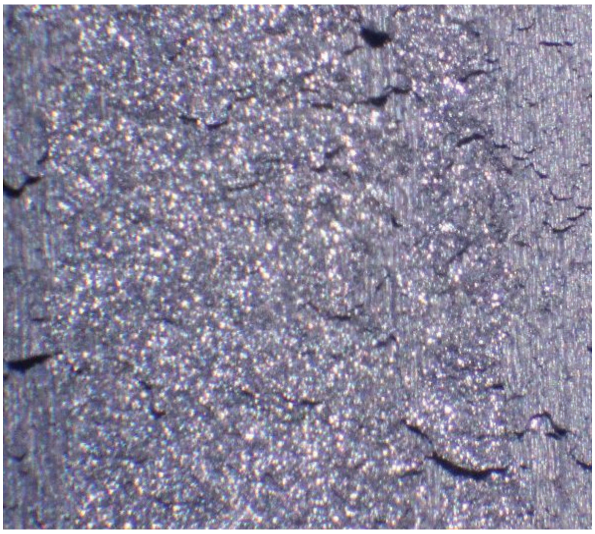
- The length of the friction path: 50 m,
- maximum sliding velocity of specimen: 0.5 ms^{-1},
- the range of specific pressure: 0.32 $N.mm^{-2}$,
- radial displacement of the specimen: 3 mm of $rotation^{-1}$,
- abrasive cloth of Al_2O_3 granularity: 200.

Three test samples were prepared for the test, each sample from each material. The abrasive wear path is 50 m of length in each interval measurement. The samples were cleaned with a subsequent weighing to electronic scales after this period, where the weight loss is detected Tab. IX. The abrasive cloth was replaced by a new cloth, when the size of the path reached 250 m.

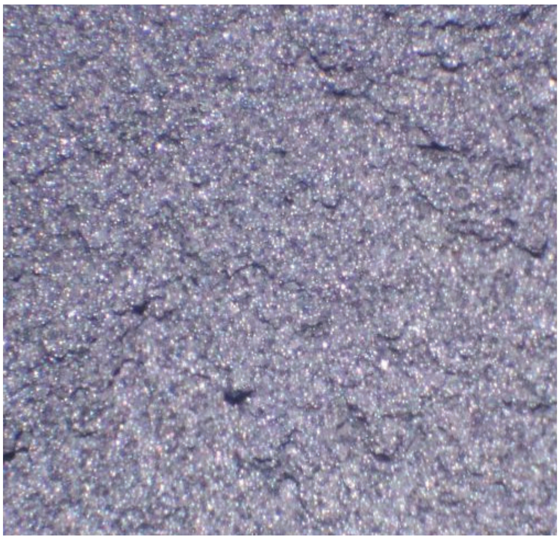
The relative wear resistance was determined by the following:

$$\text{Weight} - \Phi_m = \frac{m_{et}}{m_{vzo}}$$

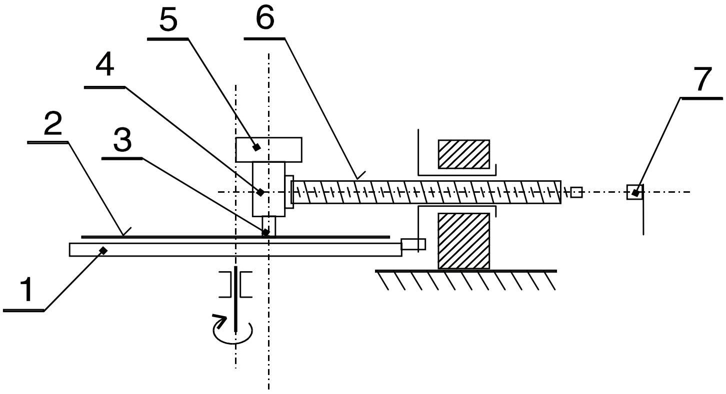
stands for:
m_{et}..... weight loss standard [mg]
m_{vzo}... weight sample loss [mg].



3: *Fracture surface of 12050 steel*



4: *Fracture surface of ADI cast iron*



5: *Test equipment with abrasive cloth*

IX: *Weight loss at abrasive cloth during the test*

Number of measurement	Weight loss at test samples [mg]					
	ADI cast iron	19436 tempered 300 °C	19436 tempered 600 °C	12050 tempered 300 °C	CDP bars(carbide)	Original material
1	214	92	108	242	102	187
2	214	95	108	244	102	187
3	216	95	109	241	102	189
4	214	94	107	244	103	189
5	216	95	108	241	102	187
Average	**214.8**	**94.2**	**108**	**242.4**	**102.2**	**187.8**
The relative wear resistance	**1**	**2.28**	**1.98**	**0.88**	**2.10**	**1.14**

Metallographic analysis

The aim of the metallographic observation is to determine steel quality. These are especially the purity and the structural components after heat treatment. Neophot 21 metallographic microscope with magnification of 800x was used for this analysis. For surface etching, was used HNO_3 with ethanol. Metallographic preparation is also used to measure the microhardness.

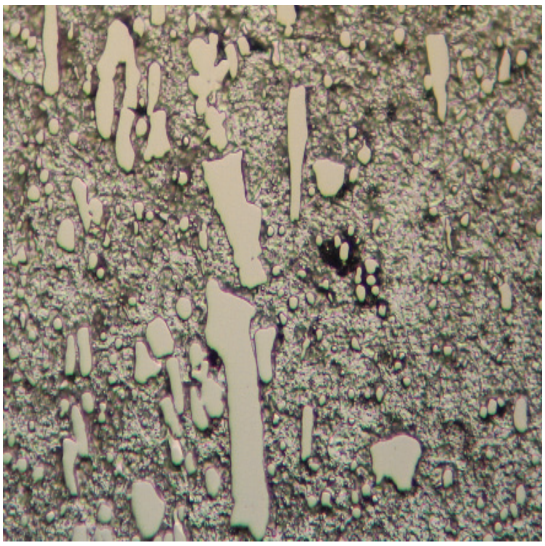
Basic structure of 19436 tempered steel is martensite matrix in which are carbides dispersed of Cr. More primary carbides are heterogeneously dispersed during tempering at 300 °C as can be seen from Fig. 6–7. The steel tempered at 600 °C shows a larger dispersion of fine carbides during the heat treatment, which are also located in the martensitic matrix. The disadvantage of this structure is common chipping carbides of the base matrix, which leads to a reduced abrasion of the material.

The structure of 12 050 steel after heat treatment and tempering temperature at 300 °C is evident from Fig. 8, which is composed of pearlite and residual ferrite. The perlite is characterized by considerable placement of lamellas. ADI cast iron is formed bainite structure apart from globular graphite.

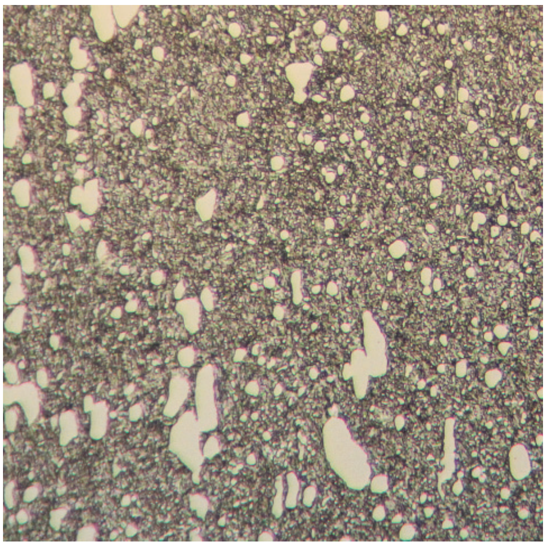
The original blade is formed mild sorbitic structure. The purity steel and heat treatment is at a high level as can be seen from Fig. 10. The weld material (CDP bars) was not found to be line carbides (as indicated by the manufacturer), only rough and unequal exclusion carbides in the base matrix. Welding technology was not stated by the producer Selected technology (TIG/MIG) influences principally ordering of carbides and their tolerance to abrasive wear (Vysočanská *et al.*, 2010).

Microhardness of tested samples

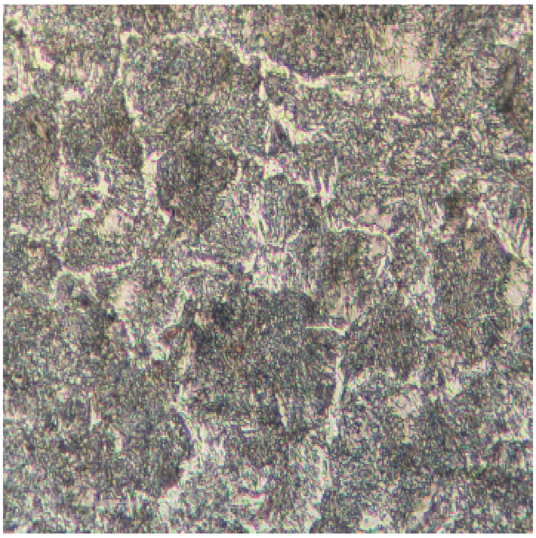
It is a classic Vickers method. The material is extruded diamond cone of vertex angle 136° power of 0.1 kp. The HV microhardness is deducted according to length of diagonals. The microhardness measurement was performed again on the set of three samples of each material. 5 values were subtracted from each sample and calculated the arithmetic average. Individual values of microhardness are given in Tab. X.



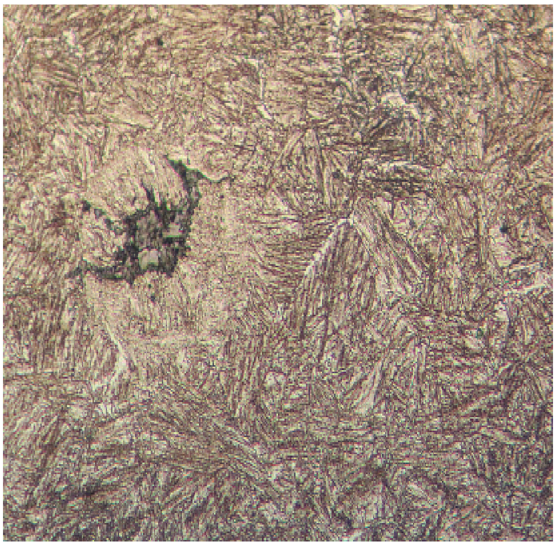
6: *19436 steel structure tempered 300 °C*



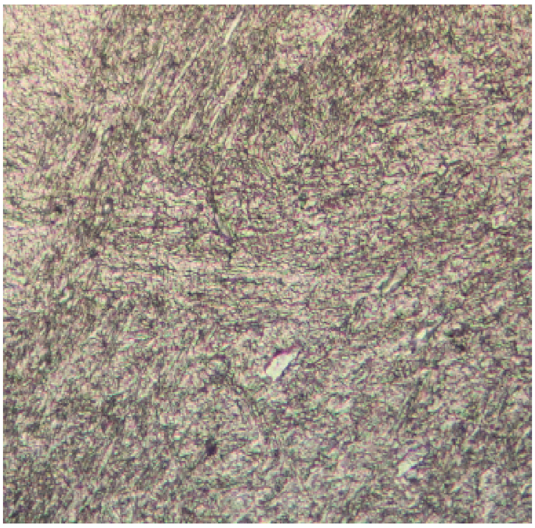
7: *19 436 steel structure tempered 600 °C*



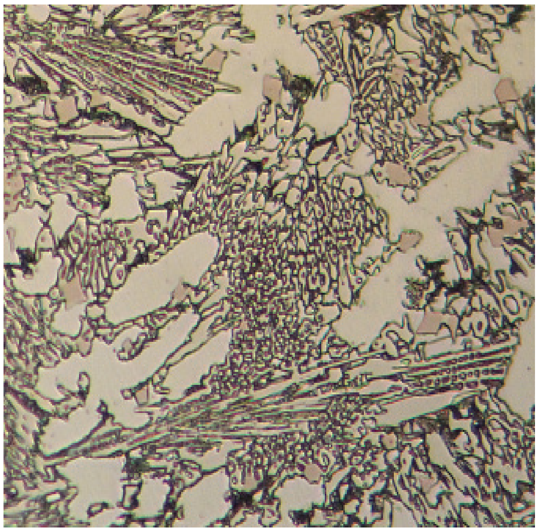
8: *12050 steel structure*



9: *ADI cast iron structure*



10: *The structure of the original material used by Gregoire Besson manufacturer*



11: *Structure of carbide weld (CDP bars)*

X: *The values of microhardness of the structural phase of the tested materials*

Used steel	Ferrite [HV]	Pearlite [HV]	Tempered Martensite [HV]	Sorbit [HV]	Bainit [HV]	Carbidy [HV]
19436 tempered 300 °C	_	_	932	_	_	1187
19436 tempered 600 °C	_	_	886	_	_	1153
12050 tempered 300 °C	273	344	_	_	_	_
ADI cast iron	_	_	_	_	527	_
CDP bars (carbide)	_	_	_	_	_	_
Original material	_	_	_	644	_	_

CONCLUSION

The abrasive wear is one of the main causes limiting tool lifetime for tillage. Considerable variability occurs abrasive action of the tool itself in real working condition. The analysis of the selected materials according to carried out laboratory tests are necessary to continue. The inverse relationship between hardness of the material and its ability to resist abrasive wear on the abrasive cloth was observed on laboratory tests.

However, hardness is not always the decisive factor that affects the wear resistance at the most.

An important factor of the wear resistance is also the microstructure of the concrete overlay (Kotus *et al.*, 2011). Reduced abrasion resistance of ferritic-pearlitic structure of heat treated 12,050 steel compared with bainitic ADI cast iron structure was proved in the tests. The hardness value at ADI cast iron is about 3 HRC units lower than 12 050. The samples of ADI iron, which were subjected to the impact toughness, showed better results about 0.56 J/mm^2 than 12 050 steel. The production of a whole subsoiler body can be suggested from this material. The main reason to use ADI cast iron is its simplicity of production and economic modesty. These two factors probably can compete with the original material, which exhibits some better values than the ADI cast iron. 19436 tool steel can be used after suitable heat treatment for deploying cutting edge casting. This material has a better abrasion resistance than CDP bars. We have to realize that mentioned material can be only produced by cutting tip of whole subsoiler, which is by its whole area located on the cutting edge of subsoiler body. The reason is to eliminate impact load working machine, as this material showed only 0.4 J/mm^2. The decisive factor for the use of each material is the amount of the skeleton in the soil.

SUMMARY

The aim of the article was metallographic, mechanical and technical analysis of the abrasive materials to manufacture subsoiler body for deep soil cultivation. The test samples were compared with the original material by Gregoire Besson company. We can say the greatest hardness at CDP bars according to the tests of hardness performed by HRC method. The half-finished product can only be recommended for the renovation worn out parts. The use of this material to the multifunctional part of the body is greatly restricted by its mightiness, which leads to an enormous increase in tensile resistance. 19 436 tool steel was thermally processed in two modes: quenching and tempering on the value of 300 °C and 600 °C. The hardness values correspond to tempered temperatures. Abrasive resistance according Tab. IX, also correlates with the measured hardness. The steel tempered at 300 °C reaches about 1.98x better wear result than the original material. Low values of impact toughness (0.4 to 0.68 J/mm^2) predispose this material only on the cutting tip, which must be firmly anchored in the blade. 12,050 Carbon steel is inappropriate for the tool for their pearlitic-ferritic structure. The values of impact strength (3.3 J/mm^2) indicate the material resistance to cracking but the abrasion resistance was about 28 mg less than the selected standard of ADI cast iron. Lobular graphite cast iron (ADI) according to each test has similar properties as the original material supplied by the manufacturer. The abrasive cloth was weight loss ADI cast of about 27 mg higher than the original material in the test. The impact strength was lower by 0.14 J/mm^2 at ADI cast iron. We can deduce the similar effect in real field conditions are on the increasing trend.

The economic aspects of the exchangeable parts for tillage always increase higher. The suitability of the selected material is a major factor in the production of these components. Similar mechanical properties of ADI cast iron are shown in the carried laboratory tests as in the original material with lower production costs.

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Address

Ing. Radek Bednář, doc. Ing. Jan Červinka, CSc., Department of Agriculture, Food and Environmental Engineering, Ing. Jiří Votava, Ph.D., Ing. Martin Fajman, Ph.D., Department of Engineering and Automobile Transport, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic, e-mail: xbedna19@node.mendelu.cz, jan.cervinka@mendelu.cz, xvotava@node.mendelu.cz, fajman@node.mendelu.cz