WEAR RESISTANT HIGH BORON STEEL FOR AGRICULTURE TOOLS

Rostislav CHOTĚBORSKÝ[1]

[1]*Department of Material Science and Manufacturing Technology, Faculty of Engineering, Czech University of Life Sciences*

Abstract
The article is focused on high boron steel applicable in agriculture mainly for agriculture tools such as chisels, rings and other. Experimental procedure included two different chemical composition of high boron cast iron with and without chromium content. The samples were in cast state and after heat treatment used in dry rubber wheel test for determination of wear resistant properties. Results show that the best wear resistant properties are received if the heat treatment and forging was used.

Key words: *High boron steel; wear resistance; agriculture tools; heat treatment.*

INTRODUCTION

Wear on tillage tools can be caused by the abrasive action of soil particles. Abrasive wear depends on the abrasive interaction, which is characterized by large surface plastic deformations occurring when two mutually sliding bodies are in contact. The phenomenon occurs when a hard body exerts a smoothing action on a softer body. Wear rate is mostly affected by soil texture, water content, bulk density, and particle angularity and the relative hardness of the tool material with respect to that of soil particles, the operating speed and depth and soil-tool pressure distribution. Especially in very abrasive soils, wear can be dramatic, indeed a tool can be worn out in one working day. An opportunity to reduce wear, largely used in the field of industrial cutting tools, is surface hardening; this can be done as a heat treatment, but above all as a superficial coating. Superficial coating techniques applied to soil engaging components include hard facing *(Jankauskas, Katinas, Skirkus, & Alekneviciene, 2014)*, edge tipping with alumina ceramic *(Müller, M., Chotěborský, R., Valášek, P., Hloch, 2013)*, boriding *(Yazici & Çavdar, 2017)* and thin coating *(Sidorov, Khoroshenkov, Lobachevskii, & Akhmedova, 2017)*.
The toughness and the hardness of the tillage tool materials should be optimized for specific operating conditions *(Abo-Elnor, Hamilton, & Boyle, 2004; Arvidsson, Keller, & Gustafsson, 2004; Cui, Défossez, & Richard, 2007)*. Steels which are often employed in the agriculture industry where soil has to be ground or transported. Although these steels are wear resistant after their heat treatment, they are low or medium carbon steel with hardness up to 55 HRC and their microstructure is tempered martensite *(D. Liu, Xu, Yang, Bai, & Fang, 2004)*. The low cost steel for agriculture tools are steel with small amount of expensive element but there are microalloyed by boron. The way how to obtain material for agriculture industry may be steels on metal matrix composite basis because material in agriculture for a tools like chisel or ploughshare must be toughness.
High-boron alloy steels (0.5 %B to 4.0 %B) are used as wear-resistant materials. At present, the change of structures and properties of high boron cast steel at different homogenization temperatures has seen relatively little study, and wear resistant high boron cast steel has yet to find broad applications *(Cen, Zhang, & Fu, 2014; Fu, Xing, Lei, & Huang, 2011; Liu, Chen, Li, & Hu, 2009)*. It is well known that boron can improve the hardenability of steels and enhance their thermal stability. The solubility of boron, however, is very low in iron, and the addition of excessive boron leads to the formation of continuous network of eutectic boride M2B (M represents Fe, Cr or Mn) along the grain boundaries, which is detrimental to the mechanical properties and results in the embrittlement of high boron Fe–B alloys *(Chen, Li, & Zhang, 2011; Y. Liu et al., 2010)*. Powder metallurgy routes have been used to produce the alloys to prevent the formation of M2B network *(Röttger, Weber, & Theisen, 2012)*. Alloying *(Baron, Springer, & Raabe, 2016; Jian et al., 2016)*, heat treatment and rare earth modification are the most common methods used to improve the toughness of high boron cast steel *(Chotěborský, Rostislav; Bryksí-Stunová, Barbora; Kolaříková, 2013; Savková, Jarmila; Chotěborský, Rostislav; Bláhová, 2013)*. Therefore, plastic deformation is also used to break up boride network. The best cutting of sheets made of high boron steel can be done by WEDM technology. Where the surface roughness can be optimized by setup of parameters *(K. Mouralova, Prokes, & Benes, 2019; K. Mouralova, Benes, et al., 2019;*

Katerina Mouralova, Kovar, Prokes, Bednar, & Hrabec, 2017). Other technological cutting can leads to crack in edges thanks to rapid heating and cooling (laser) or high wear rate of tool for machining.
The present research is to study the effect of chemical composition and heat treatment on the micro-structural transformation, hardness and wear properties of medium boron steels.

MATERIALS AND METHODS

The medium boron cast steel was melted in a 1 kg medium frequency induction furnace with SiO2 furnace lining, with charge materials of steels, ferroboron and ferroalloys. The liquid metal was super-heated at 1550-1600°C and then deoxidized with a 0.2 wt. % aluminium. Subsequently, the liquid metal was poured into a ceramics mould. The chemical composition of medium boron cast steel is given in Table. 1. It was determined with a spark emission spectrometer.
Before forging, the samples were first annealed at 1000 °C for 4 h to homogenize the chemical composition and improve hot plasticity in high boron cast steel. Process of forging is used repeatedly to break up boride network. Forging temperature of high boron cast steel according to Fe-B phase diagram changes from 900 to 1050 °C. Heat treatment included from quenching (920 °C cooling in water) and tempering (400 °C in air). Wear test was done on a three body abrasion machine based on ASTM G65. The load was 98.1 N, abrasive was sand fraction 0.2 to 0.315 mm. Test cycle of each specimen included ten times 210 m trace. The weight loss was measured after every trace on balance with accuracy 0.1 mg. Weight loss was recalculate to volume loss. To discuss the wear mechanism, worn surface was observed with SEM.

Tab. 1 Chemical composition of tested steel (wt. %), rest is Iron.

	Boron	Carbon	Neodymium	Chromium
Sample 1	0.62	0.5	0.0	0.21
Sample 2	0.61	0.52	0.38	1.12

RESULTS AND DISCUSSION

The cast alloy is generally comprised of white and white-black phases. Previous studies *(Chen et al., 2011; Z. Liu, Li, Chen, & Hu, 2008; Lv, Fu, Xing, Ma, & Hu, 2016a)* shown that white phase are borides and white-black phase is ferrite-pearlite. Fig. 1 shows microstructures of the heat treated samples. As shown in Fig. 1 cast alloy with heat treatment is comprised of white and black phases. Black phase in this case is martensite. The borides vividly present fish-bone, net-like and rod-like morphological characteristics.
Fig. 2 shows microstructures of forged samples. As shown in Fig. 2 forged alloy is generally comprised of white and black phases. White phase are undeformed borides which were cracked by forging of samples. Black phase is martensite and tempered martensite.

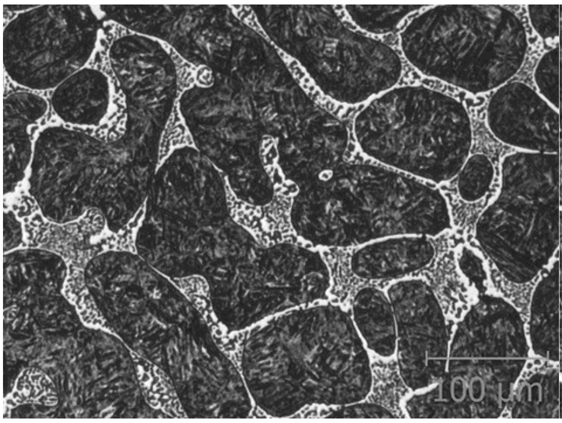

Fig. 1 Boride netlike casted sample

Fig. 2 Boride particles after forging

As a hard phase, M2B will resist the abrasive particles, protecting F-P from being a shoveled off directly. In return, F-P will support and fix M2B. Also martensite or tempered martensite show a good fix of M2B. The synergic reaction of these two constituents plays an important role in abrasive wear resistance. Richardson's theory said that the material wear resistance would be relatively poor in case of hard abrasive and can be improved effectively by hardness improvement in case of soft abrasive.
Fig. 3a shows the three body abrasive wear weight losses of Fe-B cast alloys (quenched in oil) in case of relative soft abrasive SiO2. Agriculture tool are usually made of Boron 27 steel (typical hardness is 45 HRC), this steel after heat treatment (quenching and low tempering) has a wear loss 0.12 mg per meter (mg/m). The tested high boron steel have wear loss lower then Boron 27. Results are presented in Fig. 3b, where 1 – Boron 27, 2 – sample 1 casted, 3 – sample 2 casted, 4 – sample 1 forged, 5 – sample 2 forged, 6 – sample 1 forged and quenched, 7 – sample 2 forget and quenched.

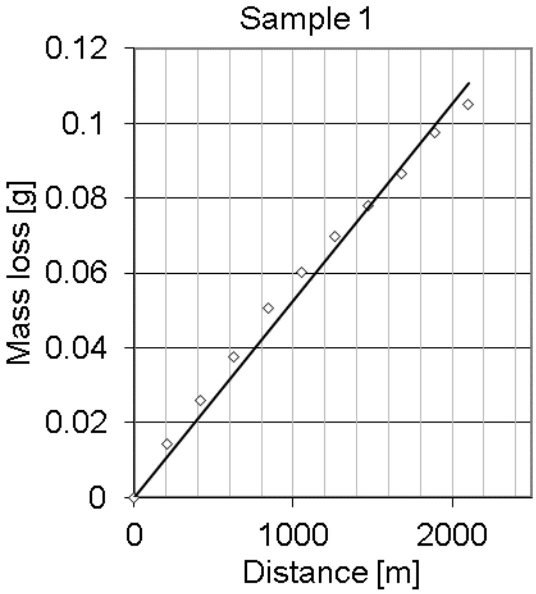

Fig. 3a Result of ASTM G65 DRWT

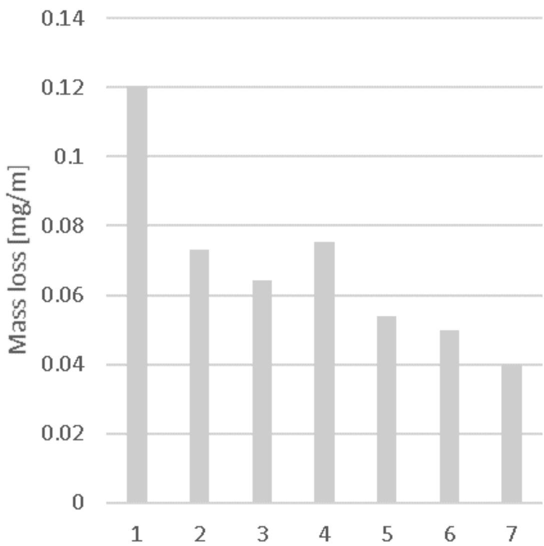

Fig. 3b Comparison of selected samples

Fig. 4. shows the worn surface of Fe-B alloy with and without forging. Worn surface in case sample without forging are covered parallel but chaotic plowing grooves and fractured borides.
Plowing grooves on the worn surfaces are relatively wide and uneven. Peeling and fragments phenomenon appear obviously for borides on the worn surface of 0Cr sample, while worn surface of 1.2Cr sample is relatively smooth. It is likely that the sharp edges and corners of SiO2 particles may be worn down during the interaction with borides. Thus, the grooves in following micro-cutting are supposed to become wider. Owning higher hardness, boride can resist the cutting by SiO2 abrasive effectively. Hence, SiO2 particles may scratch martensite firstly, resulting in their regularity of plowing grooves. For boride with high brittleness, it is easy to fracture during the interaction with SiO2 abrasive on worn surface. The fractured borides will be easily worn down in the following cratches, causing bad wear resistance of the alloy. Inreverse, borides with good toughness will retain relatively good resistance to SiO2 abrasive for along time. Wear resistance of Fe–B cast alloy will certainly make a good performance.

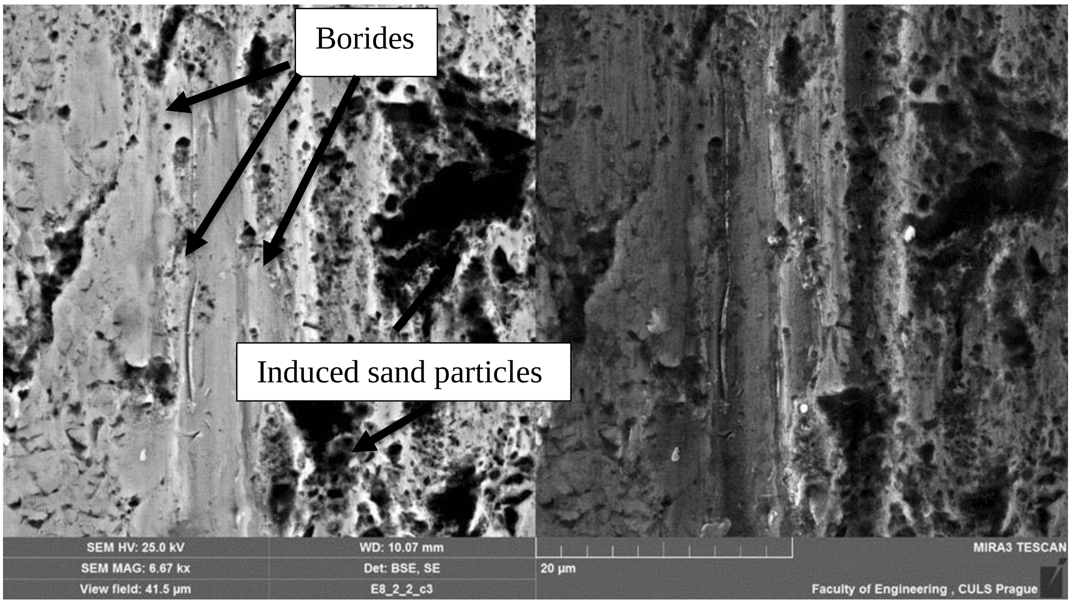

Fig. 4 Worn surface of sample 1 in casted state

Wear resistance of high boron steel so could be increased with alloying so that chromium content will be higher than tested sample. Other way can be complex alloying with aluminum and chromium which leads to higher hardness and toughness like are show in other research *(Christodoulou & Calos, 2001; Lv, Fu, Xing, Ma, & Hu, 2016b; Ren, Fu, Xing, & Tang, 2018)*. In principle it can be same such as alloying the carbide cast iron alloys for wear resistant overlay which are describe in research including wear results *(Berns, Saltykova, Röttger, & Heger, 2011; Chotěborský & Hrabě, 2013; Chotěborský et al., 2009; Kučera & Chotěborský, 2013; Lin, Chang, Chen, Hsieh, & Wu, 2010)*.

CONCLUSIONS

Hard phase of hypoeutectic Fe–C–B alloy containing 0.5 wt.% C and 0.62 wt.% B presents continues network morphology and results in poor wear resistant properties in cast state. Thermomechanical treatment can improve the morphology of hard phase and enhance the impact toughness of the alloy effectively. Hypoeutectic Fe-C-B alloys with low amount of chromium and neodymium can be one of famous and low cost material for agriculture tools like chisel, rings, etc.

REFERENCES

1. Abo-Elnor, M., Hamilton, R., & Boyle, J. (2004). Simulation of soil–blade interaction for sandy soil using advanced 3D finite element analysis. *Soil and Tillage Research*, *75*(1), 61–73.
2. Arvidsson, J., Keller, T., & Gustafsson, K. (2004). Specific draught for mouldboard plough, chisel plough and disc harrow at different water contents. *Soil and Tillage Research*, *79*(2), 221–231.
3. Baron, C., Springer, H., & Raabe, D. (2016). Efficient liquid metallurgy synthesis of Fe–TiB2 high modulus steels via in-situ reduction of titanium oxides. *Materials & Design*, *97*, 357–363. doi:10.1016/j.matdes.2016.02.076
4. Berns, H., Saltykova, A., Röttger, A., & Heger, D. (2011). Wear Protection by Fe-B-C Hard Phases. *Steel Research International*, *82*(7), 786–794. doi:10.1002/srin.201000255
5. Cen, Q., Zhang, H., & Fu, H. (2014). Effect of Heat Treatment on Structure and Wear Resistance of High Chromium Cast Steel Containing Boron. *Journal of Iron and Steel Research, International*, *21*(5), 532–538. doi:10.1016/S1006-706X(14)60083-2
6. Cui, K., Défossez, P., & Richard, G. (2007). A new approach for modelling vertical stress distribution at the soil/tyre interface to predict the compaction of cultivated soils by using the PLAXIS code. *Soil and Tillage Research*, *95*(1-2), 277–287.
7. Fu, H.-G., Xing, J.-D., Lei, Y.-P., & Huang, L.-M. (2011). A study on the wear behavior of Cast Boron Steel. *Journal of Materials Engineering and Performance*, *20*(9). doi:10.1007/s11665-010-9808-9

8. Chen, X., Li, Y., & Zhang, H. (2011). Microstructure and mechanical properties of high boron white cast iron with about 4 wt% chromium. *Journal of Materials Science*, *46*(4), 957–963. doi:10.1007/s10853-010-4840-6
9. Chotěborský, R., & Hrabě, P. (2013). Effect of destabilization treatment on microstructure, hardness and abrasive wear of high chromium hardfacing. *Research in Agricultural Engineering*, *59*(4), 128–135.
10. Chotěborský, R., Hrabě, P., Müller, M., Válek, R., Savková, J., & Jirka, M. (2009). Effect of carbide size in hardfacing on abrasive wear. *Research in Agricultural Engineering*, *55*(4), 149–158.
11. Chotěborský, Rostislav; Bryksí-Stunová, Barbora; Kolaříková, M. (2013). Effect of rare earth element on microstructure of Fe-B cast alloy. In *22nd International Conference on Metallurgy and Materials, METAL 2013* (pp. 203–207). TANGER Ltd.
12. Christodoulou, P., & Calos, N. (2001). A step towards designing Fe–Cr–B–C cast alloys. *Materials Science and Engineering: A*, *301*(2), 103–117. doi:10.1016/S0921-5093(00)01808-6
13. Jankauskas, V., Katinas, E., Skirkus, R., & Alekneviciene, V. (2014). The method of hardening soil rippers by surfacing and technical-economic assessment. *Journal of Friction and Wear*, *35*(4), 270–277. doi:10.3103/S106836661404014X
14. Jian, Y., Huang, Z., Xing, J., Liu, X., Sun, L., Zheng, B., & Wang, Y. (2016). Investigation on two-body abrasive wear behavior and mechanism of Fe–3.0wt% B cast alloy with different chromium content. *Wear*, *362-363*, 68–77. doi:10.1016/j.wear.2016.04.029
15. Kučera, M., & Chotěborský, R. (2013). Analysis of the process of abrasive wear under experimental conditions. *Scientia Agriculturae Bohemica*, *44*(2), 102–106. doi:10.7160/sab.2013.440206
16. Lin, C.-M., Chang, C.-M., Chen, J.-H., Hsieh, C.-C., & Wu, W. (2010). Microstructure and wear characteristics of high-carbon Cr-based alloy claddings formed by gas tungsten arc welding (GTAW). *Surface and Coatings Technology*, *205*(7), 2590–2596. doi:10.1016/j.surfcoat.2010.10.004
17. Liu, D., Xu, H., Yang, K., Bai, B., & Fang, H. (2004). Effect of bainite/martensite mixed microstructure on the strength and toughness of low carbon alloy steels. *Jinshu Xuebao/Acta Metallurgica Sinica*, *40*(8), 882–886.
18. Liu, Y., Li, B., Li, J., He, L., Gao, S., & Nieh, T. G. (2010). *Effect of titanium on the ductilization of Fe–B alloys with high boron content*. *Materials Letters* (Vol. 64). doi:10.1016/j.matlet.2010.03.013
19. Liu, Z., Chen, X., Li, Y., & Hu, K. (2009). High Boron Iron-Based Alloy and Its Modification. *Journal of Iron and Steel Research, International*, *16*(3), 37–54. doi:10.1016/S1006-706X(09)60041-8
20. Liu, Z., Li, Y., Chen, X., & Hu, K. (2008). Microstructure and mechanical properties of high boron white cast iron. *Materials Science and Engineering: A*, *486*(1), 112–116. doi:10.1016/j.msea.2007.10.017
21. Lv, Z., Fu, H., Xing, J., Ma, S., & Hu, Y. (2016a). Microstructure and crystallography of borides and mechanical properties of Fe–B–C–Cr–Al alloys. *Journal of Alloys and Compounds*, *662*, 54–62. doi:10.1016/j.jallcom.2015.11.171
22. Lv, Z., Fu, H., Xing, J., Ma, S., & Hu, Y. (2016b). Microstructure and crystallography of borides and mechanical properties of Fe–B–C–Cr–Al alloys. *Journal of Alloys and Compounds*, *662*, 54–62. doi:10.1016/J.JALLCOM.2015.11.171
23. Mouralova, K., Benes, L., Bednar, J., Zahradnicek, R., Prokes, T., Matousek, R., … Otoupalik, J. (2019). Using a DoE for a comprehensive analysis of the surface quality and cutting speed in WED-machined hadfield steel. *Journal of Mechanical Science and Technology*, *33*(5), 2371–2386. doi:10.1007/s12206-019-0437-4
24. Mouralova, K., Kovar, J., Prokes, T., Bednar, J., & Hrabec, P. (2017). OPTIMISATION OF WEDM SETTINGS PARAMETERS WHEN MACHINING PURE ALUMINIUM USING THE DOE. *MM Science Journal*, *2017*(05), 2105–2108. doi:10.17973/MMSJ.2017_12_201795
25. Mouralova, K., Prokes, T., & Benes, L. (2019). Surface and Subsurface Layers Defects Analysis After WEDM Affecting the Subsequent Lifetime of Produced Components. *Arabian Journal for Science and Engineering*, 1–13. doi:10.1007/s13369-019-03887-7
26. Müller, M., Chotěborský, R., Valášek, P., Hloch, S. (2013). Unusual possibility of wear

resistance increase research in the sphere of soil cultivation. *Tehnicki Vjesnik*, *20*(4), 641–646.
27. Ren, X., Fu, H., Xing, J., & Tang, S. (2018). Effect of Aluminum on Borocarbides and Temper Softening Resistance of High-Boron High-Speed Steel. *Metallurgical and Materials Transactions A*, *49*(11), 5636–5645. doi:10.1007/s11661-018-4861-3
28. Röttger, A., Weber, S., & Theisen, W. (2012). Supersolidus liquid-phase sintering of ultrahigh-boron high-carbon steels for wear-protection applications. *Materials Science and Engineering: A*, *532*, 511–521. doi:10.1016/j.msea.2011.10.118
29. Savková, Jarmila; Chotěborský, Rostislav; Bláhová, O. (2013). Effect of forging on microstructure of Fe-B cast steel. In *22nd International Conference on Metallurgy and Materials, METAL 2013* (pp. 822–827). TANGER Ltd.
30. Sidorov, S. A., Khoroshenkov, V. K., Lobachevskii, Y. P., & Akhmedova, T. S. (2017). Improving Wear Resistance of Agricultural Machine Components by Applying Hard-Alloy Thick-Layer Coatings Using Plasma Surfacing. *Metallurgist*, *60*(11-12), 1290–1294. doi:10.1007/s11015-017-0443-7
31. Yazici, A., & Çavdar, U. (2017). A Study of Soil Tillage Tools from Boronized Sintered Iron. *Metal Science and Heat Treatment*, *58*(11-12), 753–757. doi:10.1007/s11041-017-0091-3

Corresponding author:
Asc. Prof. Ing. Rostislav Choteborsky, Ph.D., Department of Material Science and Manufacturing Technology, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6, Prague, 16521, Czech Republic, phone: +420 22438 3274, e-mail: choteborsky@tf.czu.cz