

The effect of microstructure on abrasive wear of steel

A Kešner^{1,*}, R Chotěborský¹ and M Linda²

¹Department of Material Science and Manufacturing Technology, Czech University of Life Sciences Prague, Kamýcká 129, 165 21, Czech Republic

²Department of Electrical Engineering and Automation, Czech University of Life Sciences Prague, Kamýcká 129, 165 21, Czech Republic

* kesner@tf.czu.cz

Abstract. Abrasive wear of agricultural tools is one of the biggest problems in currently being. The amount of abrasive wear, depending on the microstructure, has been investigated in this work. Steels 25CrMo4 and 51CrV4 were used in this work to determine the effect of the microstructure on the abrasive wear. These steels are commonly used for components that have to withstand abrasive wear. SEM analysis was used to detect the microstructure. The standardized ASTM G65 method was used to compare the abrasive wear of steels. The results show that the abrasive wear depends on the microstructure of steels.

1. Introduction

Abrasive wear is the important problem for agricultural tools. Many producers of agricultural tools solves a way to increase the abrasion resistance of steel at the same or lower cost of manufacturing.[1, 2]. Abrasive wear causes removal of material from a surface agricultural tools and thus reduces the ability to perform the required function and it increases service life for component replacement[3, 4]. Resistance to abrasion wear can be increased by a suitable selection of material [5–7]. Material of agricultural tools, however must be chosen with regard to other mechanical properties such as strength and toughness[8]. Another option to increasing abrasion wear resistance is heat treatment[6, 9, 10]. The greatest resistance to abrasive wear is the combination of bainite and martensite microstructures[11, 12]. Isothermal quenching allows the formation of this combination of microstructures.

Soil is the main factor causing abrasive wear of agricultural tools. Other factors affecting the agricultural instrument are various barriers such as stone or large soil consolidation. For this reason, the agricultural tool must not only be resistant to abrasive wear, but must also have the required hardness and toughness. Each microstructure (in this case, bainit and martensit) has different properties[13–18].

In the works[5, 9, 11]are stated that with increasing hardness the resistance to abrasive wear increases.

The aim of this work is to evaluate the effect of the bainitic - martensitic structure on the resistance to abrasive wear of the selected steels. There are many contradictions in literature on the influence of hardness on abrasion resistance. Hardness and its depending on abrasive wear and it has been investigated in this work.

2. Material and method

Samples with dimension of 25 x 10 x 50 mm from selected steels 25CrMo4 a 51CrV4 have been used in this work. The chemical composition of steels is shown in Table 1.



Table 1. Chemical composition of steels used in this work (wt. %)

material	C	Mn	Si	P	S	Cr	Ni	Cu	Al	Mo	Sn	V	Ti
25CrMo4	0.25	0.71	0.23	0.018	0.022	1.03	0.09	0.23	0.023	0.21	0.011	0.004	0.015
51CrV4	0.53	0.89	0.26	0.012	0.025	1.02	0.08	0.13	0.028	0.02	—	0.12	—

The heat treatment procedure include: heating temperature 800 °C in air for 1200 seconds. The cooling parameters are shown in Table 2. The heat treatment parameters were taken from the TTT diagrams for the selected steels. The cooling parameters were chosen to create a combination of bainite and martensite. Steel 25CrMo4 is marked with a letter C, and 51CrV4 is marked by letter V.

Table 2. Overview of sample cooling

	cooling 1			cooling 2			cooling 3		
	temp.	medium	time [s]	temp.	medium	time [s]	temp.	medium	time [s]
C40	400	salt bath	37	400	air	163	20	air	to 20°C
C41	400	salt bath	37	20	water	to 20°C	X	X	X
V40	300	salt bath	40	300	air	1000	20	air	to 20°C
V41	300	salt bath	40	20	water	to 20°C	X	X	X
V42	400	salt bath	40	400	air	1200	20	air	to 20°C
V43	400	salt bath	40	20	water	to 20°C	X	X	X

Abrasive wear tests were performed by the ASTM G65 standardized test [20, 21]. The disk was pressed to the sample with a force of 100 N and the fraction of abrasive particle size from 0.2 mm to 0.315 mm was applied between the disc and the sample. The diameter of the rubber disc was 210 mm and the wheel width was 12.5 mm. During one measurement, the disc ran a distance of 210 meters. After each measurement, mass loss were measured on analytical balance of 0.1 mg accuracy. The mass losses were recalculated to volume loss which is indicated in $\text{mm}^3 \cdot \text{m}^{-1}$ distance. Ten measure procedures were performed for each sample.

Metallographic samples were cut in cross sectional area after full wear test. Samples were prepared for image analysis in the cut surface by grinding, polishing and etching. The grinding was done under water, followed by a diamond suspension of 9 and 3 μm . Polishing was carried out with the addition of a chemical suspension of OP-S. For etching, 2% nital (1 ml HNO_3 + 50 ml ethanol) was used.

Image analysis was performed on an electron microscope SEM (Tescan Mira 3 GXM) equipped with an energy dispersive X-ray (Oxford X-MaxN) detector. Parameters which were set on the electron microscope are shown in Figure 1. Images area (104 x 104 μm) were taken over the entire cross-section of the sample at a distance of 0.2 mm.

The image analysis was performed in Quick PHOTO INDUSTRIAL 3.1. The proportions of the phases were found - see Figure 1.

Hardness was measured on the analyzed area for abrasive wear test at a distance of 2 mm. Micro hardness was measured on the PMT 3 hardness machine using the HRC method.

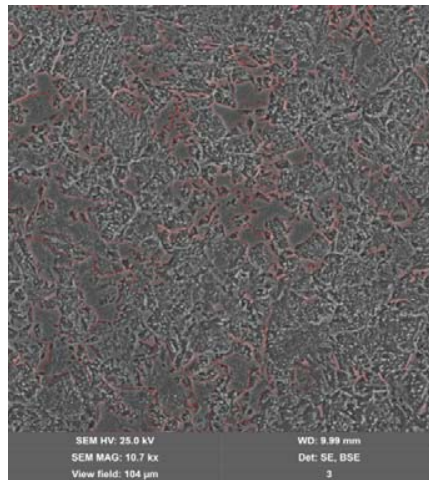


Figure1. Image analysis microstructure for V43 in Quick PHOTO INDUSTRIAL 3.1. The boundaries between the phases of bainite and martensite are indicated in red colour.

3. Results and discussion

Standardized ASTM G65 abrasive tests were evaluated. Relationships between weight losses on distances (wear traces) are shown in Figure 2. The weight loss was greatest for material 25CrMo4 (designated C). The material 51CrV4 (designated V) was significantly smaller in weight loss at the same length. The differences were minimal between 51CrV4. However, these differences are noticeably large in the overall life of the material. Differences in weight loss were statistically processed by the F-test method. There was no statistically significant difference between samples V40 and V42, samples V40 and V43, samples V42 and V43. Among the other samples, statistically significant differences were found, that is the heat treatment of these samples had a significant effect on abrasion resistance.

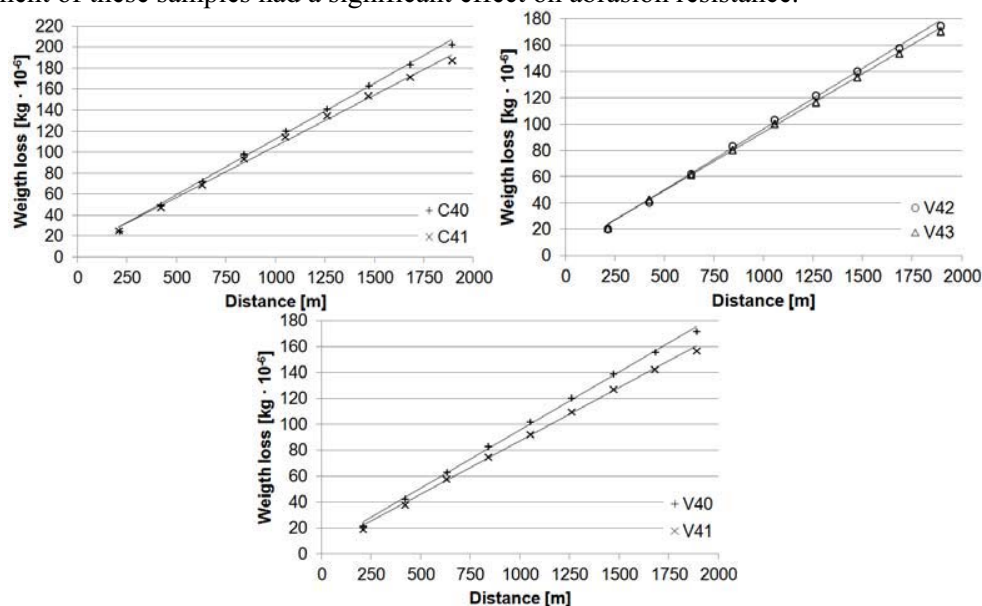


Figure 2. Dependence of weight loss on the distance traveled by the disc

The effect of microstructure on mass losses of steel was investigated. The structure of bainite and martensite was determined from the image analysis for all samples – shown in Figure 3.

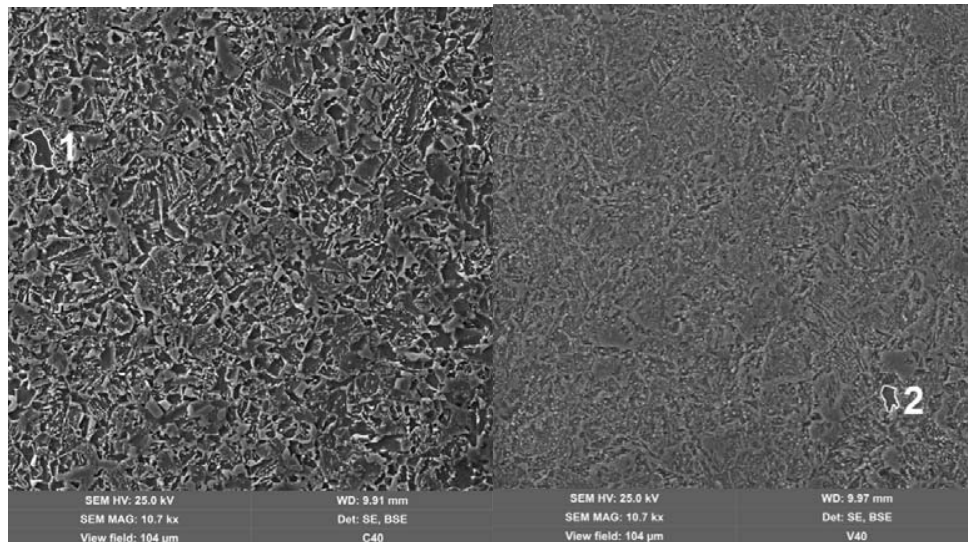


Figure 3. Microstructure images for steel. Left: Steel C40 with 12% bainite (example of bainite microstructure is marked number 1), 88% martensite. Right: Steel V40 with 99% bainite and 1% martensite (example of martensite microstructure is marked number 2).

The dependence of weight loss on the bainite structure is shown in Figure 4. The results show that the ratio volume of phases of bainite (60 to 80%) and martensite (20 to 40%) has the smallest weight loss. Increased weight loss was found in the ratio of volume phases bainite (95 to 100%) and martensite (0 to 5%) but less than the weight loss in bainite (20-30%) and martensite (70-80%) volume of bainite in martensite phase does not cover the entire distribution ratio of volume phases bainite and martensite. For this reason, it is good to determine the ratio of volume phases with 0 to 10% and 45 to 50% bainite and martensite.

The effect of microstructure on hardness is shown in Figure 4. The highest hardness of 56HRC was found highest in case if microstructure content 60% bainite and rest volume of martensite. If microstructure included 73% bainite and rest volume of martensite, a hardness of 43HRC was measured, which is less than 99% bainite where the hardness value was 45HRC. Ratio of volume phases with the difference between the hardness in dependence on the microstructure can be seen in Figure 5 on the left. A microstructure of similar composition shows great differences in hardness (for example bainite 98%).

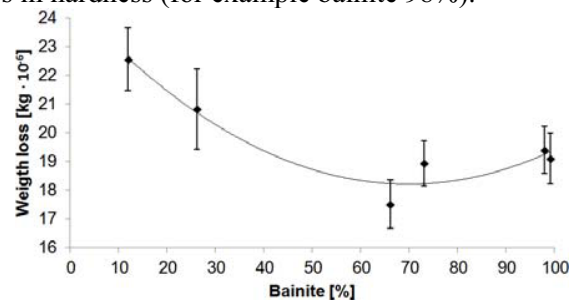


Figure 4. Dependence of weight loss on bainite structure

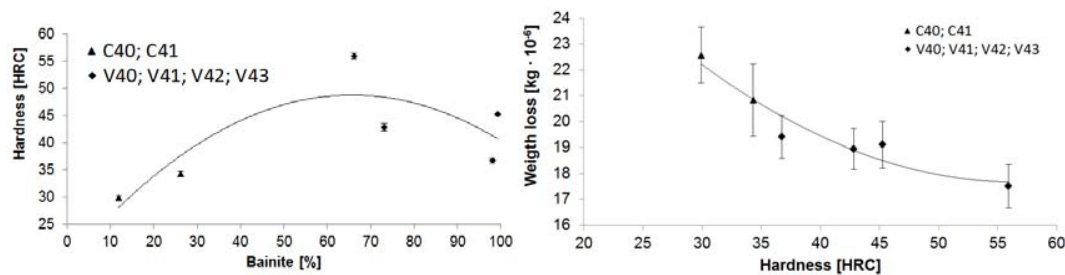


Figure 5. The dependence of hardness on the volume of bainitic microstructure

Authors AK Bhakat[8], M Vite-Torres and etc. [19], H Sabet and etc. [22] report that the greatest impact on abrasive wear has hardness. In fact, the microstructure is the most important, as the authors suggest V Jankauskas and R Skirkus [1], J J Coronado and kol. [23] and the results of this work. The results of this work it is necessary to add further representation bainite in martensite because some representation% bainite in martensite in this work was not done yet.

4. Conclusion

The results of this work show that:

- Heat treatment affects resistance to abrasion wear due to the formation of a different microstructure. Microstructure affects abrasive wear.
- Experimental measuring did show the effect of hardness on abrasive wear. With increasing hardness increases abrasion resistance.
- The 51CrV4 steel, due to its chemical composition, has greater abrasive wear resistance than 25CrMo4 steel.
- The highest abrasion resistance was measured for 51CrV4 steel containing 60-80% bainite and rest of volume martensite microstructure.

ACKNOWLEDGEMENT. Supported by Internal grant 31140/1312/3114 agency of Faculty of Engineering, Czech University of Life Sciences in Prague

References

- [1] Jankauskas V and Skirkus R 2013 Steel abrasive wear forecasting by wearing surfaces microgeometric parameters. *Mechanika*. Vol. 19, no. 4.
- [2] Chotěborský R and Linda M 2015 FEM based numerical simulation for heat treatment of the agricultural tools. *Agronomy Research*. Vol. 13, no. 3, p. 629–638.
- [3] Baburaj A, Chaudhary S S K B, Khatirkar R K and Sapate S G 2013 Abrasive Wear Behaviour of Heat Treated En31 Steel. *ISI International*. Vol. 53, no. 8, p. 1471–1478.
- [4] Chacon-Nava J G, Martinez-Villafañe A, Almeraya-Calderon F, Cabral-Miramontes J A and Stack M M 2010 Some remarks on particle size effects on the abrasion of a range of Fe based alloys. *Tribology International* [online]. Vol. 43, no. 8, p. 1307–1317.
- [5] Herian J, Aniolek K, Cieřla M and Skotnický G 2014 Shaping the structure during rolling and isothermal annealing, and its influence on the mechanical characteristics of high-carbon steel. *Materials Science and Engineering: A*. Vol. 608, p. 149–154.
- [6] Chotěborský R, Hrabě P, Müller M, Savková J, Jirka M and Navrátilová 2009 M Effect of abrasive particle size on abrasive wear of hardfacing alloys. *Research in Agricultural Engineering*. 2009. Vol. 55, no. 3.

- [7] Müller M, Chotěborský R and Hrabě P 2015 Application of overlay material on soil processing tools for purpose of increasing their abrasive wear resistance. *Listy Cukrovarnické a Reparské*. 2015. Vol. 131, no. 9–10.
- [8] Bhakat A K, Mishra A K and Mishra N S 2007 Characterization of wear and metallurgical properties for development of agricultural grade steel suitable in specific soil conditions. *Wear*. Vol. 263, no. 1–6, p. 228–233.
- [9] Jankauskas V, Katinas E, Skirkus R and Aleknevičienė V 2014 The method of hardening soil rippers by surfacing and technical-economic assessment. *Journal of Friction and Wear*. Vol. 35, no. 4, p. 270–277.
- [10] Chotěborský R and Linda M 2016 Determination of chemical content of soil particle for abrasive wear test. *Agronomy Research*. Vol. 14. Eesti Põllumajanduslikool.
- [11] Das Bakshi S, Shipway P H and Bhadeshia H K D H 2013 Three-body abrasive wear of fine pearlite, nanostructured bainite and martensite. *Wear*. Vol. 308, no. 1–2, p. 46–53.
- [12] Zhou H, Wu Z W, and Fu H A study of self-hardening bainitic cast steel. *Materialwissenschaft und Werkstofftechnik*. Vol. 44, no. 9, p. 753–759.
- [13] Richadson RCD (1967) The wear of metallic materials by soil—Practical phenomena. *Journal of Agricultural Engineering Research*. Vol. 12, no. 1, p. 22–39.
- [14] Tagar AA, JiCh, Ding Q, Adamowski J, Chandio FA and Mari I A (2014) Soil failure patterns and draft as influenced by consistency limits: An evaluation of the remolded soil cutting test. *Soil and Tillage Research*. Vol. 137, p. 58–66.
- [15] McLaughlin N B, Drury C F, Reynolds W D, Yang X M, Li Y X, Welacky T W and Stewart G (2008) Energy Inputs for Conservation and Conventional Primary Tillage Implements in a Clay Loam Soil. *Transactions of the ASABE*. Vol. 51, no. 4, p. 1153–1163.
- [16] Mikolajczak P and Napiórkowski J (2016) Analysing the reliability of working parts operating in abrasive soil pulp taking into consideration confounding factors. Vol. 18, no. 4.
- [17] Manuwa S I (2009) Performance evaluation of tillage tines operating under different depths in a sandy clay loam soil. *Soil and Tillage Research*. Vol. 103, no. 2, p. 399–405.
- [18] Aluko O B and Chandler H W (2006) A Fracture Strength Parameter for Brittle Agricultural Soils. *Biosystems Engineering*. Vol. 93, no. 2, p. 245–252.
- [19] Vite-Torres M, Vite J, Laguna-Camacho J R, Castillo M, and Marquina-Chávez A 2011 Abrasive wear on ceramic materials obtained from solid residuals coming from mines. *Wear*. Vol. 271, no. 9–10, p. 1231–1236.
- [20] Kamdi Z, Shipway P H, Voisey K T and Sturgeon A J Abrasive wear behaviour of conventional and large-particle tungsten carbide-based cermet coatings as a function of abrasive size and type. *Wear*. Vol. 271, no. 9–10, p. 1264–1272.
- [21] Chotěborský R and Linda M 2014 Evaluation of friction force using a rubber wheel instrument. *Agronomy Research*. Vol. 12, no. 1.
- [22] Sabet H, Khierandish Sh, Mirdamadi Sh and Goodarzi M 2011 The Microstructure and Abrasive Wear Resistance of Fe–Cr–C Hardfacing Alloys with the Composition of Hypoeutectic, Eutectic, and Hypereutectic at Cr /C6. *Tribology Letters*. Vol. 44, no. 2, p. 237–245.
- [23] Coronado J J, Caicedo H F and Gómez A L 2009 The effects of welding processes on abrasive wear resistance for hardfacing deposits. *Tribology International*. Vol. 42, no. 5, p. 745–749.