ΠP periodica polytechnica

Mechanical Engineering
55/1 (2011) 39–42
doi: 10.3311/pp.me.2011-1.05
web: http://www.pp.bme.hu/me

RESEARCH ARTICLE

The Effect of Microstructure on the Local Wear Behavior of Heat Treated Structural Steel

Tünde Kovács-Coskun / *Peter* Pinke

Received 2011-04-30

Abstract

It is known that the friction and wear properties of metals and alloys show a strong correlation with their chemical composition, hardness and microstructure.The aim of this work was to analyse and evaluate the correlations between the microstructure and the wear properties of low alloyed, heat treated structural steel during dry friction. Three kinds of hypoeutectoid structural steel with different microstructure were studied. For experimental purposes, a new type of micro-scale, ball-cratering tribometer and a proper wear-kinetic model based on an ordinary differential equation have been constructed. It was verified that if the process parameters (load, angular speed) are constant, the solution of the wear-kinetic differential equation could be expressed in a simple, closed form. Additionally, it was shown that (i) the heat treated steels have the highest wear resistance if the microstructure consists of only one hard martensitic phase, (ii) in case of microstructures consisting of two different phases (ferrite-pearlite, bainite, and spheroidite) the wear resistance decreases in the following order: bainite, ferrite-pearlite, and spheroidite.

Keywords

local wear · microstructure · heat treatment · wear coefficient

Acknowledgement

The authors would like to thanks the Óbuda University, Bánki Donát Faculty of Mechanical and Safety Engineering, Department of Material Science, for financial support. Also, I would like (K.T.) to thank my colleagues Dr. Réger Mihály, Dr. Réti Tamás and Dr. Sárossy György for theirs continuous support.

Tünde Kovács-Coskun
Óbuda University, Bánki Donát Mechanical and Safety Engineering,, Budapest 1081, Népszínház street. 8., Hungary
e-mail: kovacs.tunde@bgk.uni-obuda.hu

Peter Pinke
Faculty of Materials Science and Technology Trnava, Slovak University of Technology Bratislava,, Paulínska 16, 917 24 Trnava, Slovak Republic
e-mail: peter.pinke@stuba.sk

1 Introduction

In technical practice, it is very important to determine and know the durability of components or work pieces, which are modified by the choice of material, machining, and operating parameters. It is known that the friction and wear properties of metals and alloys show a strong correlation with their chemical composition, hardness and microstructure. The objective of this paper is to analyse the possible correlations between the microstructure and the wear properties of low alloyed, hypoeutectoid structural steels during dry friction [1–3]. It became clear that for the experimental purposes special testing equipment is needed, which does not initiate changes in the original microstructure of heat treated steels specimens during the wear tests. Consequently, it was necessary to develop a new type of wear testing equipment and a proper testing method, by which the undesirable effects (i.e. microstructural changes caused by intensive heat formation) can be avoided. The new experimental apparatus designated to evaluate the local wear processes occurring during dry friction can be considered as a modified and further developed version of the micro-scale, ball-cratering test equipment. This new tribometer has the following essential advantages: the wear process can be monitored continuously during the experiments; the stochastic movement of the ball makes it possible to obtain a uniform wear distribution on the ball surface, and to keep the original spherical geometry of the ball. Three kinds of hypoeutectoid structural steel were studied. Due to the different heat treatments several steel specimens were prepared with different microstructures (ferrite-pearlite, bainite, martensite, spheroidite). The microstructures of all samples were characterised by optical microscopic and hardness measurements. To evaluate the result of wear experiments performed on heat treated specimens a new wear kinetic model was developed. It has been shown that the change of wear rate (the change of wear depth) can be described by an ordinary differential equation which is compatible with the traditional Archard-model [1].

2 Theoretical background of experiments

In the present study, the results of wear experiments performed on heat treated specimens were evaluated by measuring the wear crater depth. It has been shown that the change of wear rate (the change of wear depth) can be described by an ordinary differential equation which is compatible with the traditional Archard-model Eq. (1). Fig. 2 shows the schematic arrangement of ball crater instrument used to evaluate the wear process on the specimens. The wear testing is performed without abrasive suspension (dry wear condition). The wear depth ”*h*” is measured continuously as a function of time (on-line method). Kinetics of the progress of wear process is described using a modified form of the Archard equation (1). Kinetic equation:

$$V = \frac{\pi h^2}{3}(3R - h) = KN_c S \tag{1}$$

$$h = c\sqrt{t} = \sqrt{2KN_c f}\sqrt{t} \tag{2}$$

Wear coefficient:

$$K = \frac{h^2}{2N_c f t} \tag{3}$$

Where:

- R the wear ball radius [20 mm]
- h the depth of the wear crater [μm]
- $t = 2,5$ min time of the wear process
- $N_C = 0,86$ [N] normal load
- $f = 1481$ [1/min] revolution per min
- K wear coefficient [m^2/N]
- e-diameter of the eraser [μm]
- S length of the wear [m]

$$S = 2\pi r f t \tag{4}$$

The wear crater diameter is measured by optical stereo microscopic, parameters are showed by Fig. 1.

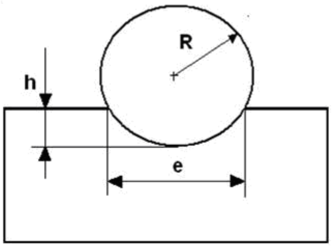

Fig. 1. The wear crater paramerers

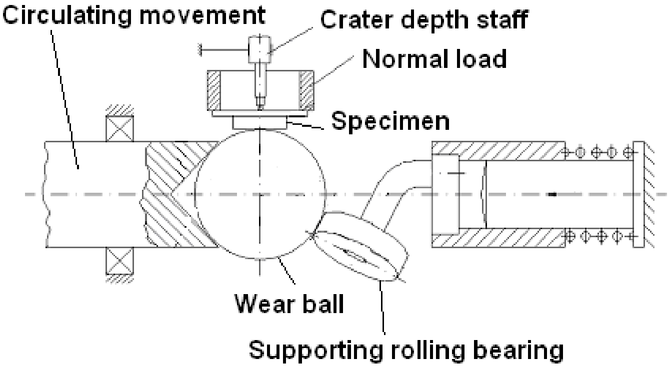

Fig. 2. Ball crater tester

3 Experimental materials and techniques

During the experiment with the ball-cratering tribometer the ball has stochastic movement affected by the friction force such way that the multiaxial variation of that force leads to random turnings of the ball. The advantage of the stochastic movement of the ball is that an automatically renewed, shape defect free surface can be obtained, the wear uniformly distributed on the whole surface of the ball and the surface roughness has spatial homogeneity. The result of the uniform wear distribution of the ball surface is that the ball original spherical geometry can be kept. Hence the volume of the wear scar of the test sample is equivalent with the geometrically explicitly defined calotte volume. This volume can be calculated continuously as a function of the time because the depth of the wear scar is being monitored during the experiment. All experiments were performed in dry conditions without any lubricant. [1] Three kinds of hypoeutectoid structural steel were studied (Tab. 1). The C45 and the 41CrS steels are temper-grade steels and the 16CrMo5 is one of the low carbon contain alloyed steel.

4 Results and discussion

A number of samples have been prepared under various heat treatment conditions to achieve different microstructures (ferrite-pearlite, bainite, martensite, spheroidite). The microstructures of all samples were characterised by optical microscopic and hardness measurements. It has been verified that if the process parameters (load, angular speed) are constant, the solution of the kinetic differential equation could be expressed in the following closed form: $h(t) = C \times t^{1/2}$ where h is the wear depth, t is the time and C is a microstructure-dependent constant. This means that the wear depth is proportional to the square-root of time. The wear coefficient K which characterizes the wear performance of heat treated steels can be calculated directly as a function of constant C estimated by the traditional least-square fitting technique Fig. 6 shows the wear coefficient in case of different microstructure. The specimens diameter are 12 mm and the high of tie cylinders are 2 mm.

Tab. 1. Chemical composition of steels.

Sign of steels	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%
16CrMo5	0,16	0,2	0,95	0,015	0,016	1,15	0,25	0,2
C45	0,43	0,23	0,53	0,012	0,012	0,28	0,07	0,14
41CrS	0,42	0,26	0,75	0,012	0,029	1,12	-	-

Heat treating technologies of different steels

16CrMo5	1. Heated 870˚C 10min/isotherm 700˚C 10min in Al bath 2. Heated 870˚C 10min/isotherm 410˚C 2min in lead bath 3. Heated 870˚C 10min/water quenching 4. Heated 870˚C 10min/water quenching/tempering 560˚C 60min Al bath
C45	1. Heated 850˚C 10min/isotherm 700˚C 1min in Al bath 2. Heated 870˚C 10min/isotherm 410˚C 2min in lead bath 3. Heated 850˚C 10min/water quenching 4.Heated 850˚C 10min/water quenching/tempering 560˚C 60min Al bath
41CrS	1. Heated 870˚C 10min/isotherm 700˚C 10min in Al bath 2. Heated 870˚C 10min/isotherm 410˚C 10min in lead bath 3. Heated 850˚C 10min/water quenching 4. Heated 850˚C 10min/water quenching/tempering 560˚C 60min Al bath

Tab. 2. Depth of the wear craters depth [μm]

Signe of the steels	16CrMo5				C45				41CrS			
Microstructures	1FP	2B	3M	4Sp	1 FP	2B	3M	4Sp	1FP	2B	3M	4Sp
h [μm]	0,6	0,4	0,4	0,6	0,8	0,3	0,3	0,6	0,7	0,3	0,2	0,6

Tab. 3. Wear coefficient in case of different microstructures

	Wear coefficient m^2/N *10^{-15}			
	Microstructures			
Signe of the steels	Ferrite-Pearlite	Spheroidite	Bainite	Martensite
16CrMo5	4,95	5,13	1,92	1,63
C45	8,2	4,46	8,66	8,33
41CrS	6,01	4,29	9,33	6,34

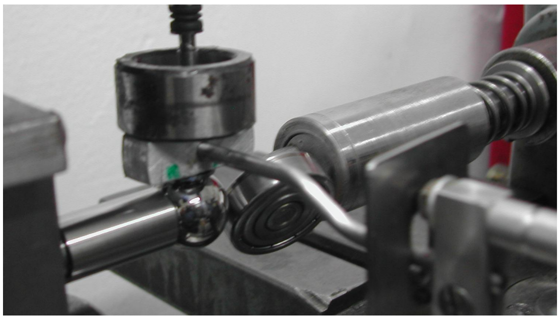

Fig. 3. Ball crater tester [1].

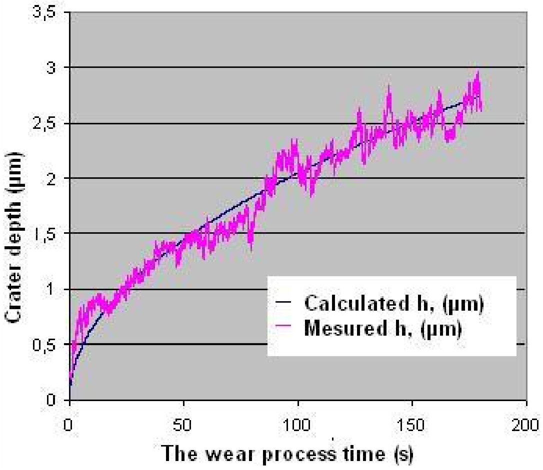

Fig. 4. The crater depth as a function of the wear process time.

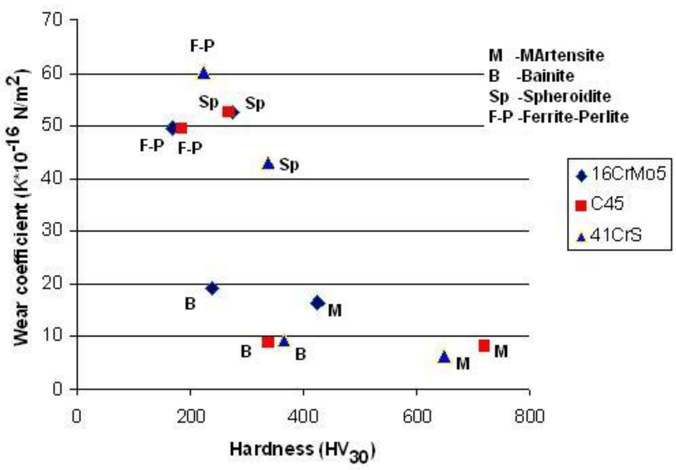

Fig. 5. Hardness and wear coefficient in case of three different steel.

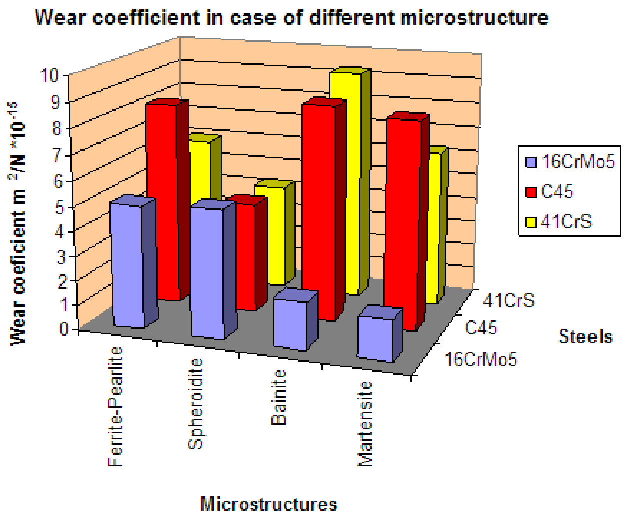

Fig. 6. Hardness and wear coefficient in case of three different steel.

5 Conclusion

It has been verified that if the process parameters (load, angular speed) are constant, the solution of the kinetic differential equation could be expressed in the following closed form: $h(t) = C_K \times t^{1/2}$ where h is the wear depth, t is the time and C_K is a microstructure-dependent constant. This means that the wear depth is proportional to the square-root of time. The wear coefficient K which characterizes the wear performance of heat treated steels can be calculated directly as a function of constant C_K estimated by the traditional least-square fitting technique.

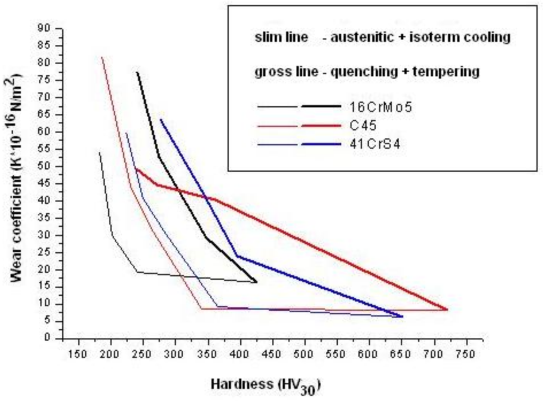

Fig. 7. Wear coefficients of the three experimented steel in one diagram.

From the results of the wear experiments the following conclusions can be drawn:

- A) The steels investigated have the highest wear resistant if the microstructure consists of only one hard martensitic phase (apart from the remaining austenite).
- B) The martensitic microstructure showed the highest wear resistance in all cases of the three studied steels (taking into account that the wear resistance is characterized by the wear coefficient K determined from experiments).
- C) In case of microstructures consisting of two different phases (ferrite-pearlite, bainite, and spheroidite) the wear resistance decreases in the following order: bainite, ferrite-pearlite, and spheroidite.

References

1 **Kovacs T**, *The effect of microstructure on the local wear behaviour of steels*, Ph.D. thesis (2007.Budapest).

2 **Bagyinszki G., Bitay E**, *Felületkezelés*, EME, Kolozsvár (2009).

3 **Richter J, Hutchings M I, Clyne T W, Allsopp D N, Peng X**, *Tribological characterization of diamond like-speed steels*, Material characterization **45** (2000), 233-239, DOI http://dx.doi.org/10.1016.

4 **Rutherford K L, Hutchings I M**, *Theory and Application of a Micro-Scale Abrasive Wear Test*, American Society for Testing and Materials (1997). West Conshocken.

5 **Bushan B**, *Modern Tribology Handbook*, CRP Press LLC, Boca Raton, London,New York, Washington DC., 2001.

6 **Gee M G, Gant A, Hutchings I, Bethke R, Schiffman K**, *Progress towards standardisation of ball cratering*, Wear **255** (2003), 1-13, DOI http://dx.doi.org/10.1016.

7 **Stachowiak G W, Batchelor A W, Stachowiak G.B**, *Experimental methods in tribology*, Tribology series **44** (2004).

8 **Kovacs T, Dévényi L**, *The analysis of the application conditions in local wear-testing phenomenon based on the theory of ball-plane impact*, Proceedings of the fourth conference on mechanical engineering (2004), 107-110.