ISSN 1392 - 1207. MECHANIKA. 2013 Volume 19(4): 486-490

Steel abrasive wear forecasting by wearing surfaces microgeometric parameters

V. Jankauskas*, R. Skirkus**
**Aleksandras Stulginskis Universitety, Studentu 11, 53361, Akademija, Kauno r., E-mail: vytenis.jankauskas@asu.lt*
***Aleksandras Stulginskis Universitety, Studentu 11, 53361, Akademija, Kauno r.,*
E-mail: remigijus.skirkus@yahoo.om

crossref http://dx.doi.org/10.5755/j01.test.10.1.5106

1. Introduction

Abrasive wear is the most intensive, loss-making mechanical wear type. Machine elements, what works in the soil wear rates can reach 12.7 mm/h [1].

For wear estimation can be used many methods, but in practice are used just few of them. Normally its selectable method, with required accuracy and what guarantees lower costs and its time efficient. These methods are micrometer, mass, artificial bases, profilography and other methods, which are selectable by required accuracy, price and speed of measurement [2].

The type and intensity of abrasive wear depends on abrasive mass (particle size, form, composition, hardness, dampness) and the wearing surface properties (composition, hardness), and also the abrasive particle and surface hardness ratio [3].

Abrasive mass abrasivity is ranked by particle hardness, size and sharpness. The harder, higher and sharper particles, then the wear is intensive [4].

Soft abrasive medium wear caused by surface multiply plastic deformation (fatigue) principle – wear is slow and acceptable [2]. Fixed abrasive particle in solid body surface creates microcuts with depth of 0.001 – 0.02 mm [5]. The wearing surface is softer then easier abrasive particle can go deepen with increasing the wear. Because of this rule, roughness of wearing soft surface is higher.

In literature [3, 5-8] the hardness is referred as the main property which has influence to abrasive wear resistance, i. e. the harder the steel surface, the higher to abrasive wear resistance it has. But actually the abrasive wear resistance determines composition and microstructure of steel [2].

Wear intensity depends directly from the metal microhardness [5]. As a rule, increasing the hardness increases the abrasive wear resistance. The abrasive particles in to the harder layer can less penetrate and less plastically deform. The exception to this rule can do microstructure features. It was found that the wear in the abrasive mass, steel 65G tempered in oil (30–35 HRC) wearing less than the steel tempered in water (58–60 HRC) [9].

Wear influence the steels tensile strength. High-tensile steel is less resistant to abrasive particles penetration into the steel, but the deformed surface returns to its original shape and not damaging the surface if it's not exceeded its elastic limit. The steels, who don't have the elastic properties, are more resistance to abrasive particle penetration, but its brittle [10].

In ideal case, intender, with significantly higher hardness than wearing surface hardness, scratching softer surface and leaves mirror trace (grove), Fig. 1.

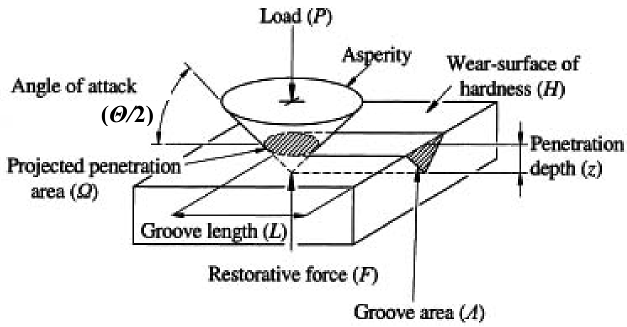


Fig. 1 Interaction between a cone shape article and flat surface [11]

Intender traces in plastic and hard (brittle) surfaces leaves different tracks (Fig. 2) [7]. In plastically surface beside trace, the dump is created while on brittle surface grove border crumbles.

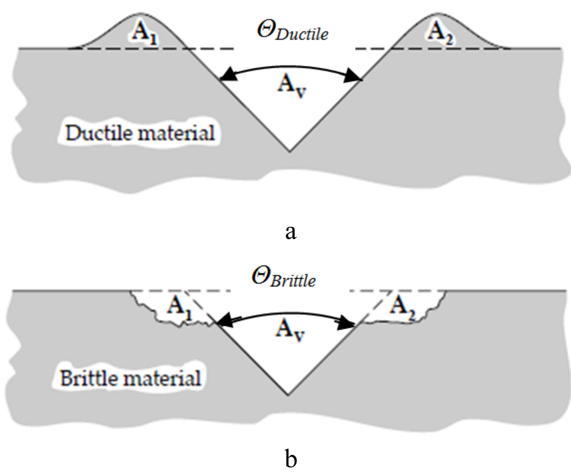


Fig. 2 Scratches formed with indenter in plastic (a) and brittle (b) surface cross-section [7]

Ductile surface wear is calculated by surface, affected by the indenter, the difference between the areas before and after the impact of inventory [7]:

$$f_{ab} = 1 - \frac{A_1 + A_2}{A_V}; \quad (1)$$

$$\Delta V_{d,ductile} = f_{ab} \frac{A_V}{A} = \frac{f_{ab} \phi P}{H_{def}}, \quad (2)$$

where: $(A_1 + A_2)$ is the cross-sectional area of the material displaced at the edges of the groove when the material is ductile; A_V is the cross-sectional area of the wear groove; f_{ab} is the ratio of the amount of material removed by the passage of a grit to the volume of the wear groove; ϕ is a factor depending on the shape of the abrasive particles; P is the externally applied surface pressure. The pressure is assumed to have a uniform value, e.g. uniformly loaded sand paper; H_{def} is the hardness of the material when highly deformed.

Brittle surface, affected by the indenter, wear is calculated by the difference between the areas before and after effects of the indenter, but because of the extra brittle fracture zones, calculation is more complex [7]:

$$\Delta V_{d,brittle} = \frac{\phi_1 P}{H_{def}} + \frac{\varphi_3 A_f D_{ab} P^{1.5} H^{0.5} \mu^2 \Omega}{K_{IC}^2}, \quad (3)$$

where: μ is the coefficient of friction at the leading face of the abrasive particles; D_{ab} is the effective size of the abrasive particles; Θ_1, Θ_3 is a factor depending on the shape of cracking during abrasive wear. For pyramidal shape particles; Ω is a parameter defined as $\Omega = 1 - exp(-(p/p_{crit})^{0.5})$; K_{IC} is the fracture toughness under tension.

Analytical evaluation of wear, when evaluating various compositions of the steels has severe limitations: an extremely different friction coefficient, underestimating the plastic deformation degree, indenter sharpness and so on [7]. It does not guarantee a minimum evaluation of accuracy.

Structural, heat-finished, mild steel (including spring-steel) hardness can reach up to 4–6 GPa.

Steels with plenty wide range of hardness has elastic properties, so it is likely that $\theta_{Brittle} > \theta_{Ductile}$, accordingly, surface, roughness top angles with differing elastic properties will be different.

Steel, impacted with indenter, elastic and brittle profiles scratches angle will vary by materials elastic deformation size. Resilience inevitable in contact: indenter - breaking the surface, therefore the material tension is greater, the greater will be the groove angle change from the indenter profile. Wherewith bigger tension difference, the greater and more accurate are calculation of difference between wear traces and wear values.

Abrasive particles abrasivity are valued by them and by wearing surface form analytically determined parameter spike parameter-quadratic fit (SPQ) [12].

Both methods are similar, they are based on the theoretical Rabinowicz method i.e. the interaction model between a precise cone shape particle and the surface [11, 13].

The profile of a wear trace is measured perpendicularly to the abrasive motion direction. The result is estimated by standard roughness parameter R_a and *SPQ* parameter [13, 14]. The *SPQ* parameter evaluates the surface profile with respect to the irregularities shape [13, 14]:

$$SPQ = \frac{1}{n}\sum_{n} cos\frac{\theta_i}{2}, \quad (4)$$

where n is the number of measured irregularities at a chosen distance; θ_i is measured angle of the i-th irregularity apex (Fig. 4).

Surface profile parameter *SPQ* is analytically determined parameter (4), for which calculation is necessary to determine the angle θ. Therefore in practice reasonable is direct relation between roughness peak angle value and wear rate value.

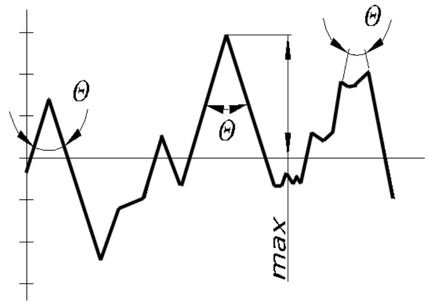


Fig. 3 Assessment of the surface profile by the *SPQ* parameter [13, 14]

SPQ parameter applied to the evaluation of different hardness steels wear (medium-carbon 45 and tool steels ХВГ) affected by abrasive wear [4]. Wear was modeled with rubber wheel according ASTM G65-94 [15].

During the test abrasive particles are pressed to the testing surface with the force, depending from load, particle size and rubber hardness. Contacting pressure force also depends from the particle shape. Particles on wearing surface sliding and rolling. Therefore more accurate result for the relation between wear and surface microgeometrical parameters will be received while performing wear test by fixed abrasive.

We accept that, abrasive paper grain average statistical peak angle perpendicular to the direction of movement the plane is constant. Therefore, the ideal inventory damage (easily cut and no deformable) surface profile will be the same. The real surface roughness profile differences will be formed by metal tension properties. Due to these metal surface roughness (scratches) properties the peak angle in perpendicular to wear direction plane will not have any relation between indenter (abrasive particles) profile angles.

The aim of this work – determine the steel wearing surface roughness peak angles relation with wear, and also creating preconditions for steel resistance to abrasive wear research methodology with wear by fixed abrasive.

2. Research methodology

For wear surface microgeometric parameters and wear relation evaluation was used low carbon boron micro alloyed steel Hardox 400 (further H400, SSAB Technology AB), medium carbon steel 45 (GOST 1050 – 88), carboniferous (spring) steel 65G (GOST 14959 – 79).

The steel composition and hardness obtained by heat treatment are given in Table 1. For heat treatment was used stove SNOL 8.2/1100 L. Sample size 20×15×7 mm.

For wear by fixed abrasive research was selected friction pair type „pin – on – drum“ (ASTM G 132–96 (2007)). By abrasive paper coated drum diameter 90 mm, applied load 28 N. The feed of 0.57 mm/rev with a drum revolving 63 min^{-1} (v = 0.3 m/s). Test repeatability – 3.

Chemical composition of the samples is determined by a spectrometer BELEC-compact-lab-N, hardness is measured with a hardness tester TK–2M. The wear is evaluated by method of mass los with the scales KERN EG 420-3NM (accuracy 0.001 g).

For research was used Al_2O_3 abrasive paper (Olimpus Abrasives Co), type KX167 with grain size P100 (average abrasive particles size 160 μm). Weared surface roughness was investigated with profilograph MahrSurf XR20. Surface profile angle perpendicular to the direction of motion of the plane was measured by processing profilogramm image with program Solid Edge ST5.

Table 1

In research used steels chemical composition and hardness

Sample	Chemical compositions of steels, wt. %								
	C	Si	Mn	Cr	Ni	Mo	B	Other	Fe
45	0.46	0.27	0.65	0.25	0.25	-	-	Cu 0.25	Remaining content
65G	0.7	0.35	1.2	0.25	-	-	-	-	
H 400	0.15	0.70	1.60	0.30	0.25	0.25	0.004	-	

Steel heat treatment and get hardness, HV				
Variant	Steel	H400	45	65G
I	Anneal 780°C	122	138	235
II	Tempered in water 870 °C and 2 h released 650°C	225	227	302
III	Tampered in oil 870°C	235	335	327
IV	Tampered in water 870°C and 2 h Released 400 °C	294	310	382
V	Tampered in water 870°C and 2 h Released 150°C	392	447	675
VI	Rolled steel (purchasing condition)	413	179	

3. Results

The wear (average values) determined in this research given in Table 2.

Table 2

In research used steel H400, 45 and 65G hardness, wear, profile peak angles, roughness

Variant	Hardness H, HV	Wear I, g	Angle θ, degree	Ra, μm
Hardox 400				
I	122	0.795	22.5	2.58
II	225	0.663	22.7	2.19
III	235	0.624	26.6	1.89
IV	294	0.652	23.7	2.02
V	392	0.589	27.2	1.83
VI	413	0.552	25	1.96
Steel 45				
I	138	0.842	26.1	2.31
II	227	0.685	30.9	2.01
III	335	0.602	35.4	1.71
IV	310	0.702	27.6	2.33
V	447	0.539	32.7	1.98
VI	179	0.774	26.5	2.23
Steel 65 G				
I	235	0.781	18.2	2.90
II	302	0.666	26.8	2.90
III	327	0.428	34.1	2.38
IV	382	0.659	24.2	2.74
V	675	0.395	34.4	1.96

By measuring sample surface profile across wear trace roughness R_a Table 2, profilogramm (view) analyzed with program Solid Edge ST5 – measured microroughness peak angles θ Table 2. It was found, that identical chemical composition, but different hardness (different structure) material wear trace is different. Abrasive particle strips for softer surface samples are rough and for harder surfaces - wear traces smoother.

Hardness H, roughness R_a and profile peak angles θ relation with wear graphically given in Figs. 4-6.

Low carbon boron micro alloyed steel Hardox 400 wear in fixed abrasive equally reliable linear characteristic describes his toughness and roughness. The harder the steel, the less it wears ($I = -0.001H + 0.84$, $R^2 = 0.84$) (Fig. 4, a). The wearing surface is rougher, the higher wear ($I = 0.28Ra + 0.07$, $R^2 = 0.84$), (Fig. 4, b). Meanwhile wearing surface profile peak angles, weakly characterizes the amount of wear ($I = -0.03\Theta + 1.37$, $R^2 = 0.49$), (Fig. 4, c). It is likely that such characteristics reason is formed very narrow wear profile peaks angles range - only 4.7 degrees (from 22.5 to 27.2).

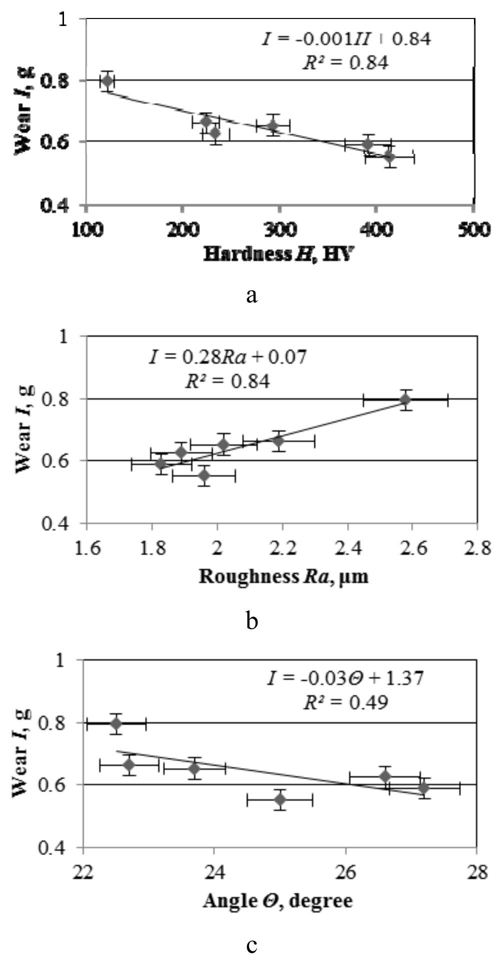
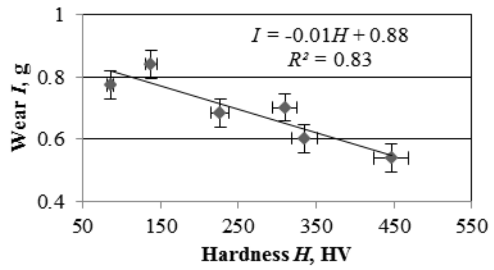
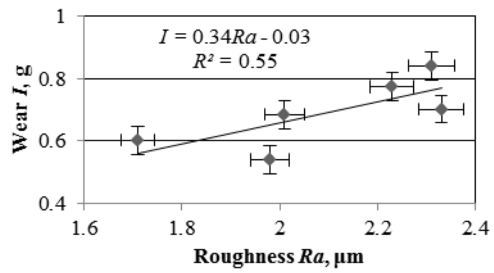


Fig. 4 Steel Hardox 400 wear and wearing surface characteristic relationship: a) hardness H; b) roughness R_a; c) profile peak angle Θ

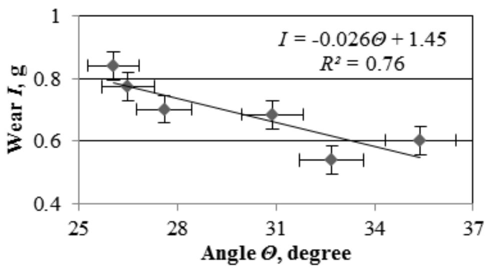
Medium carbon content steel 45 for wear resistance estimation best parameter is steel hardness ($I = -0.01H + 0.88$, $R^2 = 0.83$), (Fig. 5, a). Close to this steel wear evaluation parameter is wearing surface profile angle – the profile microroughness peak angle is bigger (tops obtuse) ($I = -0.026\Theta + 1.45$, $R^2 = 0.76$), the material has higher resistance to wear (Fig 5, c). Meanwhile, the wearing surface roughness has a weak relationship with abrasive wear ($R^2 = 0.55$), (Fig. 5, b).



a



b

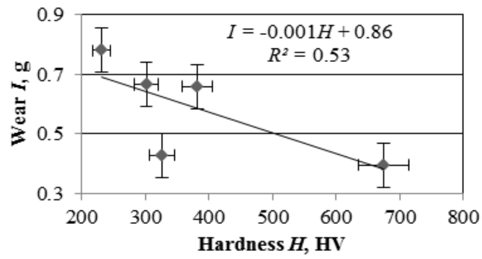


c

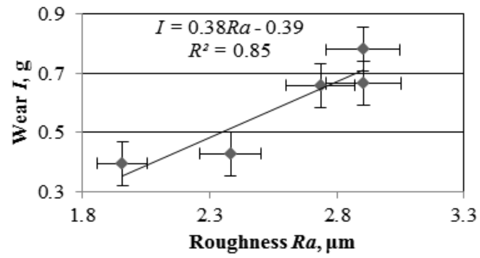
Fig. 5 Medium carbon content steel 45 wear and wearing surface characteristic relationship: a) hardness H; b) roughness R_a; c) profile peak angle Θ

Carbon (spring) steel 65G, what variety of microstructures very strongly influences the wear resistance and hardness is not a reliable parameter to describe the resistance to abrasive wear ($I = 0.001H + 0.86, R^2 = 0.53$), (Fig. 6, a). Surface roughness well describes the wear rate ($I = 0.38Ra - 0.39, R^2 = 0.85$), (Fig. 6, b). The more surface is stronger carved, the less it is resistant to wear. In this case roughness is more reliable parameter than hardness. Steel 65G resistance to wear best reflect the wearing surface profile angle. This steel roughness profile peak angle range is wide – 16.4 degree (18.2 to 34.4). The more profile tops angle smaller, the surface wears more intensively ($I = -0.024\Theta + 1.24$, $R^2 = 0.95$) (Fig. 6, c).

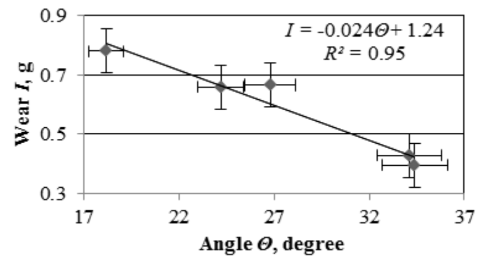
The results suggest that the steel abrasive wear can be predicted not only by the hardness, but also by the roughness of the wear track and the wear track profile tops size of angles. The more surface is resistant to abrasive wear the trace smoother and vice versa. Evaluation of carbon steel wear trace by profile tops angle established reliable relationship ($R^2 = 0.95$), the relationship between the wear rate and surface profile angles. Therefore, carbon steel with a wide hardness range resistance to wear by fixed abrasive is appropriate by the wear trace profile tops angles.



a



b



c

Fig. 6 Carbon steel 65G wear and wearing surface characteristics relationship: a) hardness H; b) roughness R_a; c) profile peak angle Θ

4. Conclusions

Low carbon steel wear by fixed abrasive can be predicted from their hardness and wearing surface roughness, medium carbon steel – hardness and wearing surface profile tops angles, carbon steel – wearing surface roughness and wearing surface profile tops angles.

The higher the evaluated material hardness difference, the wider range of profile tops angles, the better can be forecast wear. Wear evaluation by surface roughness or wearing surface profile tops angle has the comparative evaluation (practical) sense, for example, evaluation under the same conditions working parts for resistance to abrasive wear, where other estimation methods is complicated or impossible.

References

1. **Pigors O.** 1993. Werkstoffe in der Tribotechnik Reibung, Schmierung und Verschleissbeständigkeit von Werkstoffen und Bauteilen, Leipzig: Deutscher Verlag für Grundstoffindustrie, 546p.

2. **Blau, P.** 2010. ASM Handbook, Vol. 18. Friction, Lubrication, and Wear Technology. ASM International, 1879p.

3. **Khrushchev, M.M.; Babichev, M.A.** 1970. Abrasive Wear, Moscow: Science, 252p. (in Russian).

4. **Jankauskas, V.; Kreivaitis, R.** 2007. Study of wear prediction by applying surface microgeometric parameters, Mechanika 5(67): 65-70.

5. **Garkunov, D.N.** 2001. Triboengineering: Wear and No – Wear, Moscow: MCXA, 616p. (in Russian).

6. **Heinrich, R.** 1995. Untersuchungen zur Abrasivitat von Boden als Verschleissbestimmender Kennwert, Technische Universitat Bergakademie Freiberg, 99p.

7. **Stachowiak, G., Andrew, B.** 2005. Engineering Tribology, Third Edit, Elsevier, 832p.

8. **Tkachiov, V.N.** 1995. The efficiency of machine parts under conditions of abrasive wear, Moscow: Mashinostroenie, 336p. (in Russian).

9. **Jankauskas, V.; Žunda, A.; Šlapelis, A.** 2004. Steels Lubor 044, 65G and L53 wear in abrasive environment research, Agricultural Engineering 36(3): 63-74 (in Lithuanian).

10. **Callister, William D.** 2012. Fundamentals of Materials Science and Engineering Fifth edition, 4th edition, New York: John Wiley & Sons, 936p.

11. **De Pellegrin, D.V., Stachowiak, G.W.** 2001. A new technique for measuring particle angularity using cone fit analysis, Wear 247(1): 109-119. http://dx.doi.org/10.1016/S0043-1648(00)00512-3
12. **Stachowiak, G.W.** 2000. Particle angularity and its relationship to abrasive and erosive wear, Wear 241(2): 214-219. http://dx.doi.org/10.1016/S0043-1648(00)00378-1
13. **Stachowiak, G.W.** 2006.Wear: Materials, Mechanisms and Practice, Wiley. 458p.

14. **Hamblin, M.G., Stachowiak, G.W.** 1997. Characterisation of surface abrasivity and its relation to two-body abrasive wear, Wear 206(1-2): 69-75. http://dx.doi.org/10.1016/S0043-1648(96)07323-1
15. **ASTM.** ASTM G65 - 04(2010) Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus, 12p.

V. Jankauskas, R. Skirkus

PLIENŲ ABRAZYVINIO DILIMO PROGNOZAVIMAS PAGAL DYLANČIO PAVIRŠIAUS MIKROGEOMETRINIUS PARAMETRUS

R e z i u m ė

Straipsnyje pateikta skirtingo kietumo mažaanglio Hardox 400, vidutinio anglingumo 45 ir anglingo 65G plienų, dilimo paviršių mikrogeometrinių charakteristikų analizė. Plienai termiškai apdirbti siekiant maksimalaus jų kietumo intervalo. Dilimo į įtvirtintą abrazyvą tyrimai atlikti pagal ASTM G 132–96 (2007), naudojant trinties poros tipą „pin–on–drum“. Nustatytas nudilimas, kuris vertintas sąryšyje su tyrime naudotų plienų kietumu, dilimo pėdsako šiurkštumu, mikronelygumų viršūnių kampais.

Tyrimų rezultate nustatyta, kad esant dilimui į įtvirtintą abrazyvą mažaanglių plienų nudilimą galima prognozuoti pagal jų kietumą ir dylančio paviršiaus šiurkštumą, vidutinio anglingumo plienų – pagal kietumą ir dylančio paviršiaus mikronelygumų viršūnių kampus, anglingų plienų – pagal dylančio paviršiaus šiurkštumą ir dylančio paviršiaus mikronelygumų viršūnių kampus Θ. Šių parametrų tarpusavio ryšys tiesinis. Pastarasis vertinimas yra aukšto patikimumo, tiesinės charakteristikos $I = -0.024\Theta + 1.24$, $R^2 = 0.95$.

Šie rezultatai teikia galimybę palyginti vienodos sudėties, bet skirtingo kietumo plienų, naudojamų vienodomis abrazyvinio dilimo sąlygomis, nudilimą, kai galimi skirtingi vertinimo kriterijai - kietumas, šiurkštumas ir dylančio paviršiaus mikronelygumų viršūnių kampai Θ.

V. Jankauskas, R. Skirkus

STEEL ABRASIVE WEAR FORECASTING BY WEARING SURFACES MICROGEOMETRIC PARAMETERS

S u m m a r y

Article presents varying hardness of low carbon Hardox 400, medium-carbon 45 and carboniferous 65G steels, wear surfaces the microgeometric characteristics analysis. Steels are thermally processed to reach their maximum hardness range. Wear by fixed abrasive research was performed according the ASTM G 132 – 96 (2007), by using friction pair type „pin–on–drum“. Established wear, which was evaluated in connection with the study used steel hardness, wear trace roughness, profile tops angles.

The research result established that with wear by fixed abrasive low carbon steels wear can be predicted from their hardness and wearing surface roughness, medium carbon steel – hardness and wearing surface profile tops angles, carbon steel – wearing surface roughness and wearing surface profile tops angles Θ. These parameters interconnection is linear. This latter evaluation is highly reliable, linear characteristic $I = -0.024\Theta + 1.24$, $R^2 = 0.95$.

These results give opportunity to compare equal composition, but different steel hardness, used by the same abrasive wear conditions, wear, when are available different estimation criteria – hardness, roughness and wearing surface profile tops angles Θ.

Keywords: abrasive wear, wear by fixed abrasive, microgeometric parameters, steel Hardox 400.

Received
Accepted