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IMPACT OF THE FORM FACTOR OF THE ABRASIVE PARTICLES OF THE SOIL ON THE INTENSITY OF THE TILLING MACHINES TOOLS WEAR

Abrasive wear is one of the most common types of wear, about 50% of all machine parts failures fall on this type of wear. Study of the regularities of the abrasive wear process and search of the methods how to avoid the negative consequences is very important problem. In agricultural production working tools directly contacting with the soil undergo extensive abrasive wear. In the process of the operation of the tilling and seeding machines tools with the soil the wear of the surface occurs as a result of the interaction with the minerals, hardness of which is higher that the hardness of the metal. The form of the abrasive particles greatly influences the mechanism and intensity of the abrasive wear of the tilling and seeding machines tools.

The aim of the given study is the determination of the form factor and soil abrasion of the abrasive particles of soils in Ukraine as well as the changes of the form coefficient of the abrasive particles as a result of the interaction with working tools of the tilling and seeding machines .

Study of the form of the abrasive particles was carried out at all the type of soil in Ukraine.

As a result of the research, carried out, it was determined that the form factor of the soil abrasive particles in Ukraine is within the limits of 78.9...487.65. Form factor of the abrasive particles for large fractions of the abrasive material is smaller than for small fractions. The value of the form factor of the abrasive particles in the tilling layer is less by 11.43...47.71% as compared with the abrasive particles in the raw layer. The regularity of the considerable decrease of the form factor of the abrasive particles of large fractions as compared with small abrasive caused by the interaction with the tools of tilling and seeding machines is observed. Wear capacity of the abrasive particles increases with the increase of the form factor. Direct dependence between the decrease of the wear capacity of the soil and decrease of the form factor of the abrasive particles is not observed due to the complexity of the structure and self organization of the soil environment.

Key words: *abrasive particle, dimension, form factor, wear, soil, surface.*

Introduction

In the developed countries the expenditures, stipulated by the consequences of the abrasive wear represent 1 – 4% of GDP [1]. Numerous studies are devoted to the investigation of the mechanism of the abrasive wear and the impact of various factors on this mechanism but still much remains to be studied in this process. In agrarian sphere the tools of tilling and seeding machines are subject to the abrasive wear as they contact with the soil.

These machines occupy one of the leading positions in the structure of the machine and tractor fleet of modern agricultural enterprises. Loss of the operation state during field work can influence greatly the yield of the crops. Accordingly, the search of the ways aimed at increase of the tilling machines longevity is of great importance for the agricultural complex of the developed countries.

As it is seen from the studies [2, 3, 4], three groups of methods can be applied to improve the durability and wear resistance of the agricultural machinery tools: technological, constructive and operational. The studies [5] show that knowledge in the sphere of tribology obtained during the last 50 years are realized in industry in the ratio: 80% – construction and 20% – operation. The authors refer to the report of P. Jost at the conference in London, held in 2016, under the term construction he meant the application of the construction and technological methods of the wear resistance increase [5]. Regarding such distribution for the tools of the tilling and seeding machines the share of the operation methods will be smaller. For the introduction of the operational methods aimed at the increase of the wear resistance of the tilling and seeding machines tooling it is necessary to know the properties and characteristics of the soil environment.

Soil as the element of the tribosystem has not been studied completely, that is why, it is difficult to determine the exact impact of all the properties and characteristics of this abrasive mass on the intensity of tools wear. Great contribution in the study of the soil environment as the element of the tribosystem was made by: M. M. Severniov [6], V. M. Tkachov [2], D. B. Berenshtein [7], M. M. Tenenbaum [8, 9], B. I. Kostetskyi [4] and others.

In the process of tilling and seeding machines tools interaction with the soil the surface wear occurs mainly as a result of the contact with minerals, hardness of which is higher than the hardness of the metal (HV 7...11 GPa, according to V. M. Tkachev [2], HV 8...12, according to N. A. Kachynskyi [10], data of other authors do not differ greatly).

High abrasive capacity of the soil is explained by the presence of particles (quartz, mica, etc), having not only high strength but also high crushing energy. The tensile energy for the covalent bonds inherent to the abrasive particles of quartz and mica is $E_{nom\ min}$=9...7.5 eV, where as for the metal bonds this index is $E_{nom\ min}$=3...2 eV. The form of the abrasive particles greatly influences the mechanism and intensity of the abrasive wear. It was established previously that the sharper abrasive particles in the soil are, the more intensive is the abrasive wear of the metal.

Analysis of the previous research

For the assessment of the form of the abrasive particles of the same fraction M. M. Tanenbaum suggested the criterion, called the abrasive particles form factor [8]:

$$K_{\phi} = \frac{M(n_i) M(D_i - d_i)}{M(R_i)}, \tag{1}$$

where $M(n_i)$, $M(R_i)$ and $M(D_i$-$d_i)$ – mathematical expectation for the number of vertexes, their radii and diameters difference of the circles, described around the contour and inscribed in the contour of the grain.

Study of the abrasive particles form factor of different materials showed that the abrasive (quartz), widely spread in the soil has low form factor: at the fraction size of 0,2…0,315 mm – K_f is 14.4; fraction size of 0,315…0,4 mm – K_f = 9.9; fraction size of 0,4…0,63 mm – K_f = 8.4; fraction size of 0,63…0,8 mm – K_f = 6.85; fraction size of 1,0…2,0 mm – K_f = 1.97 (results are presented for the quartz sand from the Liubernetskyi open-cut-mining). Experimentally it is determined [8] that if K_f = 11.25 direct destruction of the material does not take place, irrespective of other characteristics of the abrasive mass.

D. B. Bereshtein [7] for the soil suggested another form for the determination of the form factor of the abrasive particles:

$$K_{\phi} = \frac{M(N)}{M(r) \times M(B/L)}, \tag{2}$$

where N – is the number of grooves; r – radii of the grooves; L – the greatest value of the longitudinal dimension; B – the greatest value of the transversal dimension [7].

The studies showed that the wear intensity (I_a) increases with the increase of the form factor of the abrasive particles (Fig. 1).

The analysis of the research, carried out earlier, demonstrated that with the increase of the form factor of the abrasive particle wear capacity of the soil increases. Up till now the following points remain undetermined:

– form factor of the abrasive particles of the soil in Ukraine;

– change of the form factor of the abrasive particles by their fractions and by the depth of their occurrence in the soil;

– regularities of the change of the abrasive particles form factor as a result of their interaction with the metal surface of the tools;

– wear capacity of the abrasive particles with different form factors for the steels, used for the manufacture of the disk tools of the tilling and seeding machines (steel 65Г and 28MnB5).

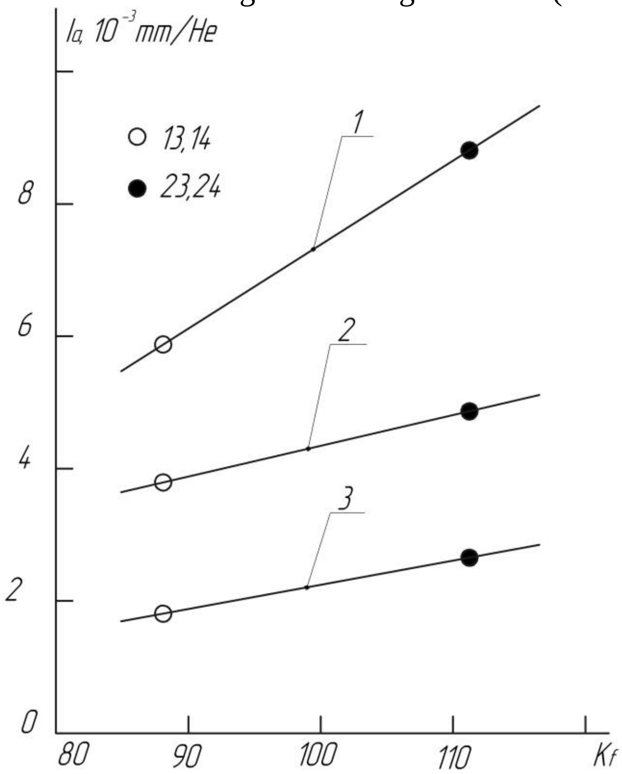


Fig. 1. Dependence of the wear intensity I_a of the plough share on the form factor of the soil abrasive particles K_f. Material of the share – steel Л-53: 1 – hardness 35-40 HRC, 2 – 45-50 HRC, 3 – blade of the share is strengthened with the hard alloy ПГ-УС 25

Aim of the study – determine the form factor and wear capacity of the abrasive particles of the soil of Ukraine as well as change of the form factor of the abrasive particles as a result of the interaction with the tool of the tilling and seeding machines.

Methods of the research

For the determination of the form factor of the abrasive particles on various types of the soil the map of the soils of Ukraine was analyzed, the regions for taking samples (samples were taken in six regions) were determined.

Soil probes were taken at each of the plots in three points on the diagonal. For the determination of the form factor of the abrasive particles and impact on the form of the regular interaction with the surface of the tilling and seeding machines tools the samples were taken at such depth: soil surface, 200 mm, 400 mm, 600 mm and 800 mm.

Abrasive particles were allocated from the previous samples, applying the technique [10]. Form factors of the abrasive particles were determined by the formula, suggested by D. B. Bernshtein (Formula 2) [7]. Measurement of the geometric parameters was performed according to the scheme, presented in Fig. 2.

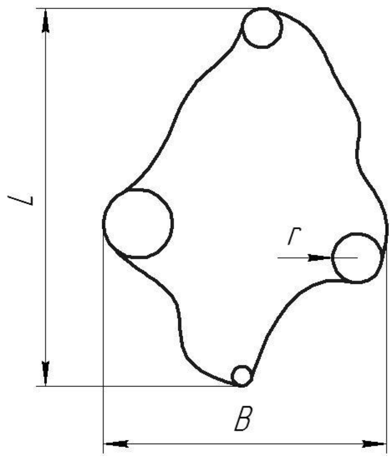


Fig. 2. Geometrical parameters of the abrasive particle: *L* – the greatest value of the longitudinal dimension; *B* – the greatest value of the transversal dimension; *r* – radii of the grooves

For obtaining the geometrical parameters of the abrasive particles, it was taken photo by means of the microscope SIGETA CAM-03, parameters were determined by means by the computer program COMPAS-3D V16.

Form factor of the abrasive particles of the soil was determined for different fractions: fraction 1 – up to 0.10 mm; fraction 2 – 0,10...0,25 mm; fraction 3 – 0,25...0,50 mm; fraction 4 – 0,50...0,75 mm; fraction 5 – 0,75...1,00 mm. For each sample the form factor was determined by 20 abrasive particles of each fraction.

For the investigation of the form factor change as a result of the interaction of the abrasive particles with the steel surface the laboratory studies were carried out. In the process of such experiment it is necessary that the mechanism of the abrasive particle interaction with the surface of the steel sample was the same as in the process of the abrasive soil interaction with the tools of the tilling machines. For this purpose the method of torsion shear should be improved Fig. 3.

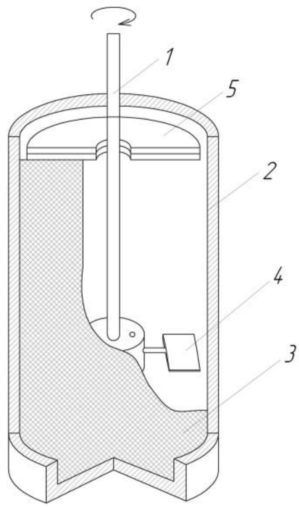


Fig. 3. Testing scheme applying the improved torsion shear method: 1 – samples shaft holder, 2 – cylinder, 3 – abrasive mass, 4 – samples, 5 – multi-sectional disk that creates the necessary density of the abrasive mass

In the traditional method the samples rotate at a constant speed in the form of the heaped abrasive mass, put into the cylindrical barrel. In the process of the operation the abrasive mass loosens and its density changes, that leads to the change of mechanism and character of the abrasive wear, that is why, it is suggested to install multi sectional disk above the abrasive material which will create the necessary density of the abrasive mass and specific pressure on the sample by means of its weight change.

The slope of the samples in the rotation plane is 17º, this intensifies the wear process and promotes the mixing of the abrasive environment.

The drive of the shaft-holder (Fig. 4, a) was realized from the spindle of the vertical boring machine-tool 2Е78П (Fig. 4, b), this enables to change the speed of the sample motion from 15.5 to 715.9 m/min (from 0.26 to 11.94 m/sec).

a)

b)

Fig. 4. Installation for the study of the samples wear resisting , applying the improved torsion shear method

As the abrasive mass the quartz sand was used as it is the main abrasive, wearing the surface of the tilling machines tools.

Discussion

The photo of the abrasive particles, taken by means of the microscope SIGETA CAM-03, is presented in Fig. 5.

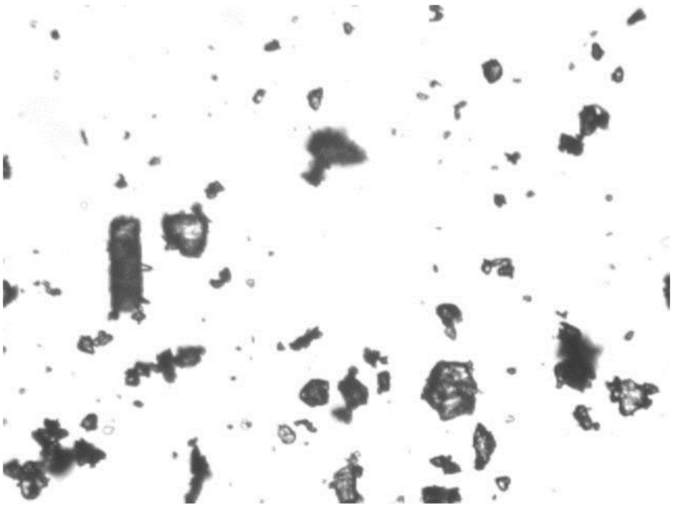


Fig. 5. Abrasive particles of the soil (sod-bleached soils, depth of the sampling 200 mm)

The result of the form factor determination of the abrasive particles for the soils in Ukraine are presented in Table 1.

Table 1

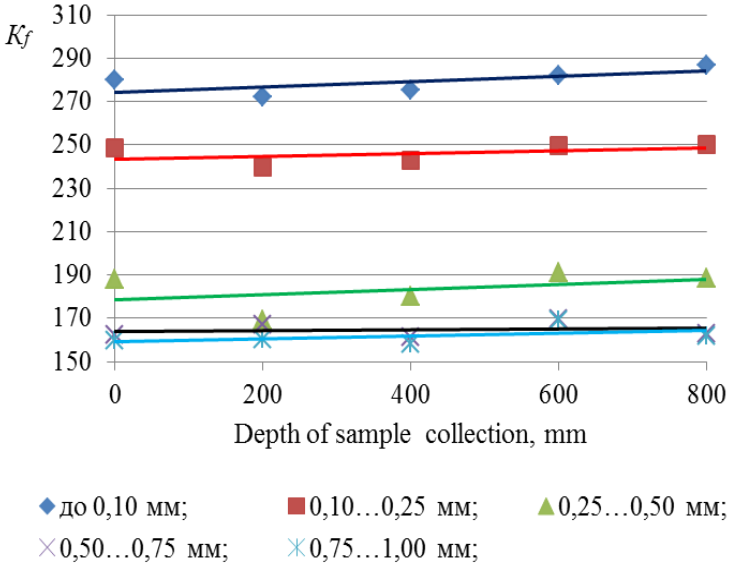
Results of the study of the particles factor K_f

Soils	Abrasive particles fraction	Soil surface	Depth 200 mm	Depth 400 mm	Depth 600 mm	Depth 800 mm
1. Meadow soils, medium textured loam	to 0,10 mm;	436,32	427, 74	487,43	488,35	487,65
	0.10…0.25 mm;	328,75	336,97	381,43	379,17	386,24
	0,25…0,50 mm;	115,76	119,76	189,70	181,48	184,56
	0,50…0,75 mm;	105,72	109,50	227,46	216,79	218,72
	0,75…1,00 mm;	78,90	77,61	210,58	214,56	214,31
2. Sod-podzolic soils, light loamy	to 0,10 mm;	239,68	227,89	269,76	271,62	271,73
	0,10…0,25 mm;	194,32	201,34	237,65	238,23	235,48
	0,25…0,50 mm;	112,69	109,86	175,47	181,53	174,97
	0,50…0,75 мм;	92,47	91,53	159,87	160,57	156,37
	0,75…1,00 mm;	81,83	83,29	144,83	143,75	146,79
3. Shallow black soils, forest steppe, light clay	to 0,10 mm;	294,38	289,56	346,67	351,92	338,16
	0,10…0,25 mm;	276,16	281,24	330,41	326,18	339,71
	0,25…0,50 мм;	128,94	122,63	179,01	180,69	175,61
	0,50…0,75 mm;	118,93	123,89	164,92	170,34	167,90
	0,75…1,00 mm;	89,79	94,31	153,79	160,31	154,39
4. Bleached soils, medium-textured loam	to 0,10 mm;	346,79	336,82	418,23	429,47	428,81
	0,10…0,25 mm;	287,38	291,03	358,94	361,09	369,24
	0,25…0,50 mm;	165,34	158,45	201,76	193,21	196,34
	0,50…0,75 mm;	110,28	113,89	170,26	176,34	169,23
	0,75…1,00 mm;	100,29	96,49	156,29	164,42	158,37
5. Ordinary forest black soils, light clay	to 0,10 mm;	274,56	269,23	299,57	292,31	295,34
	0,10…0,25 mm;	183,27	186,98	243,18	237,79	247,51
	0,25…0,50 mm;	164,29	160,37	220,34	218,51	222,57
	0,50…0,75 mm;	129,17	136,23	218,93	215,34	210,43
	0,75…1,00 mm;	98,18	96,59	182,54	176,21	189,35
6. Chestnut soils, heavy loam	to 0,10 mm;	369,56	367,89	406,57	409,87	400,29
	0,10…0,25 mm;	245,69	249,65	298,67	301,45	295,81
	0,25…0,50 mm;	145,87	142,87	201,31	210,19	205,79
	0,50…0,75 mm;	109,84	109,01	192,34	190,23	187,16
	0,75…1,00 mm;	91,75	94,51	176,79	180,45	177,10
7. Samples are taken in the woodland, sod podzolic soils, light loamy	to 0,10 mm;	279,89	271,93	275,49	281,87	286,79
	0,10…0,25 mm;	248,63	239,58	242,65	249,67	249,95
	0,25…0,50 mm;	187,79	169,36	179,93	191,28	188,63
	0,50…0,75 mm;	162,46	166,91	161,47	169,47	162,74
	0,75…1,00 mm;	159,48	160,34	157,98	168,91	161,62

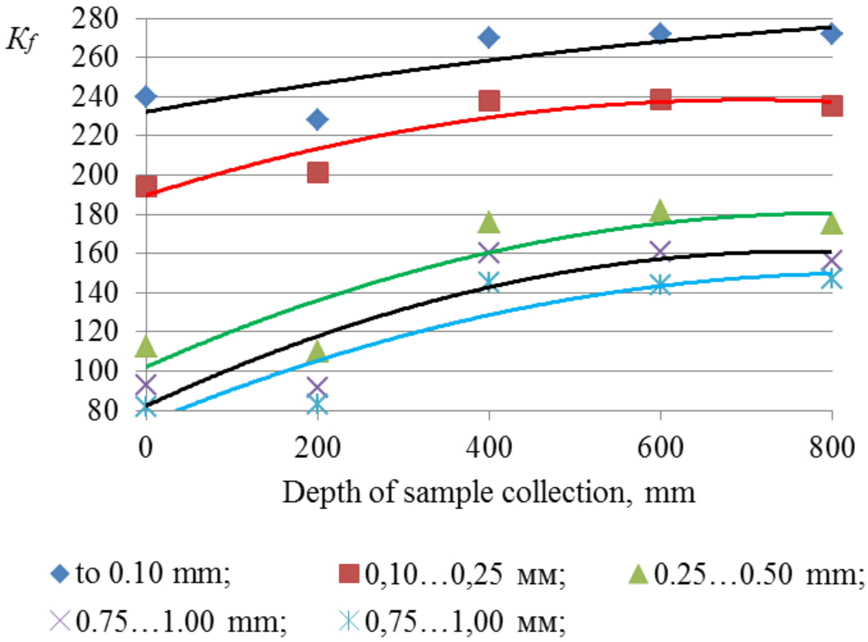
It can be stated that on the depth of the arable layer (sample from the soil surface and sample from the depth of 200 mm) the form factor of the abrasive particles for the determined fractions is the same. Their values differ for the soil №1 by 1.63...3.34%, for the soil №2 – by 1.01...4.91%, for the soil №3 – by 1.64...4.89%, for the soil №4 – by 1.25...4.16%, for the soil №5 – by 1.62...5.18%, for the soil №6 – by 0.45...2.92%. It is also proved by the lack of the direct dependence of the value of the form factor of the abrasive particles on the depth of the arable layer.

The decrease of the form factor of the abrasive particles as a result of the constant interaction with the tools of the tilling and seeding machinery is obvious (Table 2). Destruction of the sharp grooves and rounding of the abrasive particles occurs not only due to the interaction with the surface of the tools but as a result of the interaction between the abrasive particles on the condition of the aggregate state change in the process of the soil cultivation.

The confirmation of the form factor of the abrasive particles decrease as a result of the repeated interaction with the working surfaces of the agricultural machines is the absence of such dependence (Fig. 6) for the abrasive particles, contained in the woodland soil (sample of the soil №7). Sample of the soil №7 was taken at the distance of 500 m from the experimental field, where samples of soil №2 were taken.



a)



b)

Fig. 6. Change of the form factor of the abrasive particles of the soil (K_f) depending on the depth of the sample collection: a – soil sample №7; b – soil sample №2

It should be noted that the form factor for the abrasive particles of the coarse fraction changes greater than for the abrasive particles of the fine fraction for all the types of soil (Fig. 7). The regularity, presented in Fig. 6, can be explained by the fact that the abrasive particles of the small size are unaffected by the intensive destruction as a result of the interaction with the working tools of the agricultural machines, because:

– have higher strength;

– absence of the internal faults in the structure of the crystal;

– have smaller mass;

– due to the small dimensions, they do not work on the surface of the tool as the fixed abrasive.

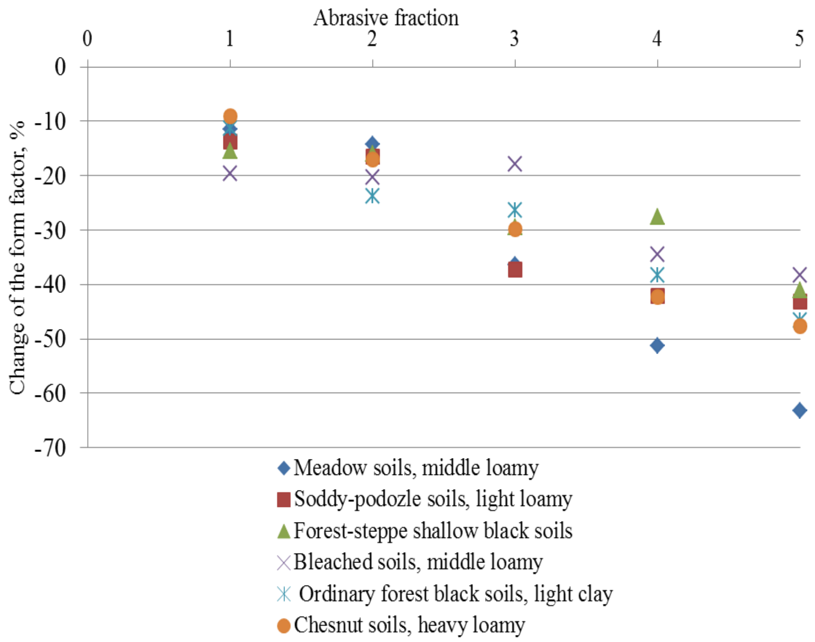


Fig. 7. Change of the form factor of the abrasive particles (K_f) as a result of the interaction with the tools depending on the dimensions of the abrasive particles: 1 – up to 0.10 mm; 2 – 0.10...0.25 mm; 3 – 0.25...0.50 mm; 4 – 0.50...0.75 mm; 5 – 0.75...1.00 mm

For the determination of the form factor of the abrasive particles impact on the intensity of the working surfaces wear rate laboratory studies were carried out on the steels 65Г, 45 and 28MnB5 (Fig. 8). Quartz sand from three deposits (Tarasivske, Ignatpilske, Irshanske) is used as the abrasive, particles of the fraction 0.50...1.00 mm were taken from these deposits. Form factor of the abrasive particles was for the Irshanske deposit – 98.71, for Tarasivske deposit – 114.18, for Ignatpilske deposit – 163.72.

At it is seen from the graph (Fig. 8), as a result of the increase of the form factor of the abrasive particles the intensity of the steels wear increases. For the steels of lower quality (steel 45) wear intensity growth rate is by an order higher than in the steels, used for the manufacturing of the disk tools of the tilling and seeding machines. This dependence can be explained by the change of the surface wear mechanism, as on the surface of the steel 45 with the increase of the form factor of the abrasive particles the area, where there are the signs of microcutting process, increases.

As a result of the studies the change of the form factor of the abrasive particles for the quartz sand, used as the abrasive environment, was determined. The form factor of the abrasive particles decreased for all the samples of the quartz sand : for Irshanskyi deposit the form factor was 79.14 (-19.82%), for Tarasivskyi deposit – 89.79 (-21.36%), for Ignatpilskyi deposit – 113.72 (- 30.54).

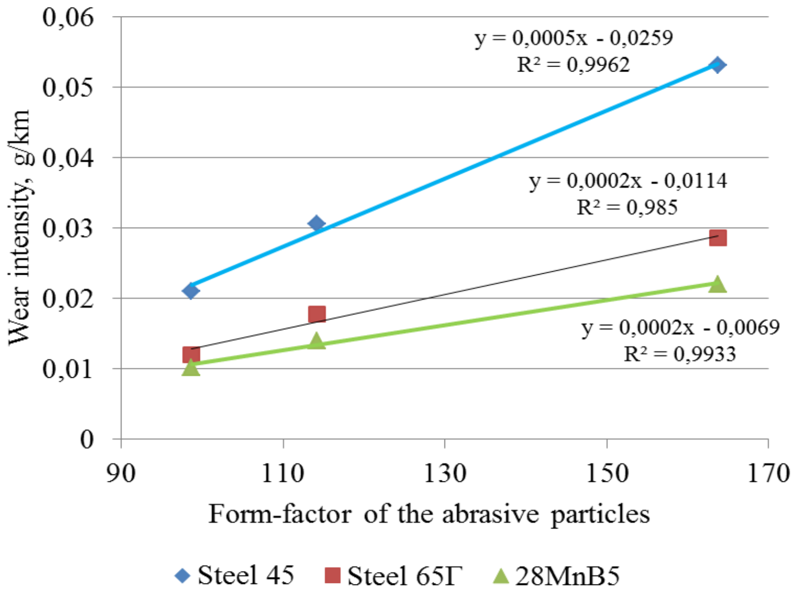


Fig. 8. Impact of the form factor of the abrasive particles on wear intensity (samples of the steel 45 and 65Г were subjected to volume quenching at the temperature of 810…830 ºC and medium-temperature tempering with the accurate soaking at the temperature of 460…480 ºC, samples of the steel 28MnB5 were made of castings for disk tools which are to be subjected to complex thermal and grit blasting)

We observe the dependence of the considerable decrease of the form factor as a result of the interaction with the working surface and the interaction between the abrasive particles for the abrasive particles with great form factor (Fig. 9). This process can be explained by the intensive interaction with the surface of the studied sample and emergence of the boundary stresses due to the small area of the sharp edges of the abrasive particles.

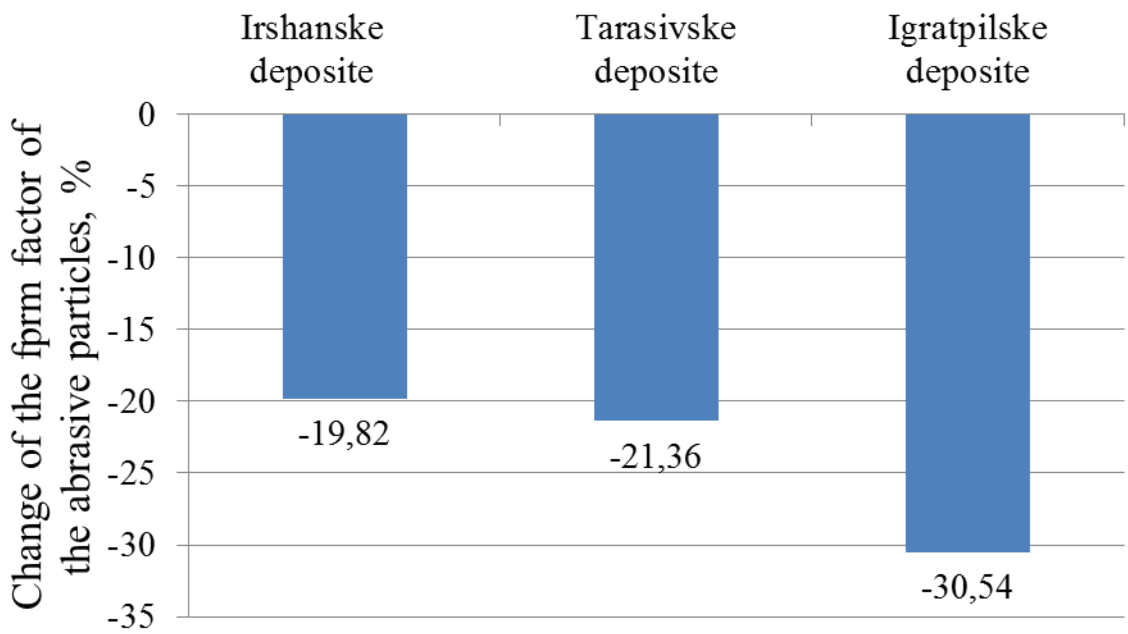


Fig. 9. Change of the form factor of the abrasive particles by the results of the laboratory studies of the steels wear intensity

Decrease of the form factor of the abrasive particles in the arable layer as a result of the long-term usage of the soil resources will lead to the decrease of the abrasive ability but the abrasive particles of the more rounded form are not able to retain humidity in the soil that leads to the rapid evaporation of water and this, in its turn, leads to the increase of the soil hardness, degree of the abrasive particles binding and increase of the wear intensity, that is why, the problem of the selection of optimal agricultural terms of soil cultivation for the reduction of the intensity of the tools of tilling and seeding machines wear will complicate with every decade.

Conclusions

As a result of studies, carried out, it was established that the form factor of the abrasive particles of the soils of Ukraine is within the limits of 78.9...487.65. The form factor of the abrasive particles for coarse fraction of the abrasive is less than for fine fractions. The value of the form factor of the abrasive particles in the arable layer is less by 11.43...47.71% as compared with the abrasive particles in non-arable layer. We observe the regularity of the considerable decrease of the form factor of the abrasive particles of the coarse fractions as compared with fine abrasive as a result of the interaction with the tools of tilling and seeding machines. Wear ability of the abrasive particles increases with the increase of the form factor. The direct dependence between the decrease of the wear capacity of soils and decrease of the form factor of the abrasive particles is not observed due to the complexity of the structure and self organization of the soil environment.

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