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INFLUENCE OF THE PLOUGH WITH TEKRONE MOULDBOARDS AND LANDSIDES ON PLOUGHING PARAMETERS

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This paper is dedicated to Tekrone composite material utilization in agricultural machinery. In terms of its technical properties, tekrone is very similar to steel 60 that is used for production of plough mouldboards and landsides. However, Tekrone shows more preferable characteristics, because its friction coefficient (k_f) is 2.6 times lower in contrast to steel 60. This fact indicates that the draft resistance can be decreased by replacing the plough mouldboards and landsides made of steel 60 with their counterparts made of Tekrone. This science hypothesis was confirmed by experimental investigation results. Analyses showed that utilization of plough with Tekrone mouldboards and landsides instead of steel ones significantly reduces their sticking to the wet soil. This results in a "soil moves over plough mouldboard surface" process instead of a "soil moves over soil" process. The plough draft resistance was decreased by 13.6% after replacement of the steel equipment with Tekrone one. Simultaneously, the performance of new tractor-plough aggregate was increased by 12.6%, the specific fuel consumption was reduced by 11.8%, and the preserving probability of the agrotechnological ploughing depth tolerance (±2 cm) was increased from 88% to 93%.

Keywords: ploughing; friction coefficient; draft resistance; soil sticking

Ploughing is one of the most frequently utilized tillage processes. In practice, ploughs are responsible for performance of this process. Although the history of their appearance and development is quite long, plough construction was fundamentally modified only. The majority of these were aimed at the plough draft resistance reduction, since even today, ploughing is the most energy-intensive tillage operation.

The task of the plough draft resistance reduction has been dealt with by different methods, e.g. Araya and Kawanishi (1985) supplied compressed air into the working zone of the ploughshare via special nozzles. As a result, the significant horizontal cracks were formed, which crumbled the soil and reduced the draft resistance of the soil tillage implement. Other researchers (Loveykin and Dyachenko, 2012; Niyamapa and Salokhe, 2000) used a mechanical vibration of the plough bottoms in a horizontal plane. For this purpose, they used hydraulic vibrators that oscillated the plough bottoms at a frequency of 6–8 Hz.

Furthermore, Romanuk et al. (2016) also investigated the influence of the plough vibrations on the horizontal plane on its draft resistance. Such plough oscillations were provided by polygonal support wheels. As a result, the plough produced oscillations with a frequency of 6–7 Hz, resulting in the draft resistance reduction.

In addition to this, Lukashok and Kornev (2009) mounted the rollers into the three-bottom plough mouldboards. This reduced the soil frictional force acting on the plough mouldboards and the draft power necessary for its movement was reduced by 3 kW.

Belousov and Trubilin (2013) tried to decrease the draft resistance by mounting additional flat ploughshares – these were mounted on the left of the main ploughshares and crumbled the soil, which was being tilled during the next working pass. As a result, the plough draft resistance was reduced.

Searching for methods for the plough draft resistance reduction has led to designing of the plough disk variant (Nkakini and Akor, 2012). There were attempts to reduce the plough draft resistance by changing the parameters of its mouldboards and shares (Bulgakov et al., 2019; Godwin, 2007; Shmulevich et al., 2007). However, these ploughs are not widely applicable, because they mix the upper and lower layers of arable soil horizon, which is undesirable.

Discover of the electro-hydraulic effect allowed creation of a complex of electro-hydraulic ploughs (Utkin, 1986). Utilization of these tillage implements allowed decreasing their draft resistance and promoting the assimilation of plants with different chemical elements. Primarily, the amount of dissolved forms of nitrogen increased in the soil due to electro-hydraulic influence. However, such tillage implements were and are very expensive.

Other researchers (Pavlyuk and Sotnikov, 2014) tried to decrease the plough draft resistance by using

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Fig. 1 Tekrone plough mouldboards and landsides

electric osmosis, ultrasound, and magnetic field. In spite of a significant decrease in draft resistance of tillage implements, these technical decisions are not used due to their difficult implementation and high cost.

There is a cheaper option to reduce the plough draft resistance – specifically by replacing the steel surface of the mouldboard with a material that shows a lower soil friction coefficient.

Attempts to use the Teflon mouldboards were already patented in 1959 (Owen et al., 1959). Good results were obtained with the mouldboards made of polyethylene 211-07 (Kiryukhin et al., 1974). The researchers experimentally found that the draft resistance in sucha plough showed a decrease, provided its performance increased by 11% and the fuel consumptionwas reduced by 6% at minimum.

This paper presents the results of practical implementation of another method for the plough draft resistance reduction. It is essentially based on replacing of steel plough mouldboards and landsides with equipment made of Tekrone (Fig. 1).

Material and methods

Tekrone is a thermoplastic-based composite material created in Belgium. Comparison of its main physical-technical characteristics with steel 60, which is traditionally used for manufacturing of the plough mouldboards and landsides, is presented in Table 1.

Table 1 Tekrone physical-technical characteristics in comparison to steel 60

Item	Value	
	Tekrone	Steel 60
Bulk density (kg·m^{-3})	930	7800
Normalized hardness	60 (by Shor)	217 (HB)
Tensile modulus (MPa)	720	920
Tensile creep modulus (MPa)	460	590
Tensile yield strength (MPa)	17	17
Relative tensile strain (%)	20	19
Static friction coefficient (k_f)	0.20	0.52

The bulk density represents the very first indicator in which these materials significantly differ: steel 60 shows at least 8 times higher bulk density than Tekrone and thanks to this fact, steel 60 shows higher normalized hardness (see Table 1). Simultaneously, data analysis shown in Table 1 indicates that the rest of compared indicators are the same.

Aforementioned physical-technical properties of Tekrone mainly characterize the durability and reliability of the products made of it. Considering the decreasing of the plough draft resistance, the Tekrone friction coefficient (k_f) is of higher significance. The (k_f) value for new material is lower by 2.6 times than that for steel 60 (Table 1). This is largely due to the fact that Tekrone is characterised by rather low adhesion. In terms of interaction of a body with a surface of low adhesion, the friction is minimal (Abbaspour-Gilandeh et al., 2018; Poláková and Dostál, 2019). In addition to this, Tekrone shows high hydrophobic properties, which are very important during the soil ploughing with moisture of 20% and less.

All in all, this fact suggests that the plough with Tekrone mouldboards and landsides shows lower draft resistance.

In order to determine the influence of material of the mouldboards and landsides on the plough draft resistance, a strain-measuring method was utilized (Fig. 2).

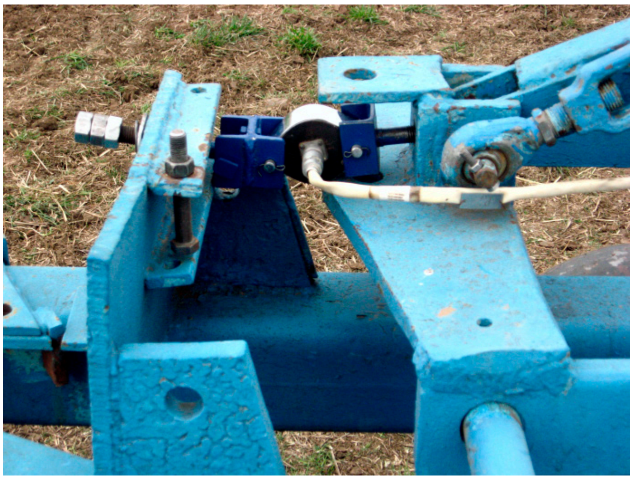

Fig. 2 Strain-measuring method applied to plough with Tekrone mouldboards and landsides

The electrical signal from the strain-measuring plough was transferred to an analogue-to-digital converter and

Fig. 3 Tractor XTZ-170 during strain measurement

then to computer. This test was conducted on a XTZ-170 series tractor equipped with an engine YMZ-236 (Fig. 3).

The strain-measuring plough was adjusted to the ploughing depth of 25 cm. The measurement quantity of this parameter was equal to 100 and the step of these measurements was equal to 0.2 m.

To determine the width of the tractor-plough set before its passage from the furrow wall at a distance *L* (during field tests, this distance equalled to 2 m), 200 pegs were installed with 1 m steps. After the tractor-plough set passed from each peg to the wall of newly laid furrow, the distances (h_i) were measured (Fig. 4).

The working width of the tractor-plough set (B_p) was calculated on the basis of the following expression:

$$B_p = L - h_i \qquad (1)$$

For estimation of an inner nature of the ploughing width and depth oscillations, the normalized correlation functions and spectral density were used.

The tractor with plough moved on the same gear in all experiments. During execution of the field experimental studies, soil moisture and bulk density were measured five times.

The former was determined by means of well-known thermostat-weight method. The latter was defined utilizing the special densitometer (Nadykto and Kotov, 2015). The peculiarity of this device lies in the fact that its electronic scale immediately shows the soil bulk density in g·cm^{-3}.

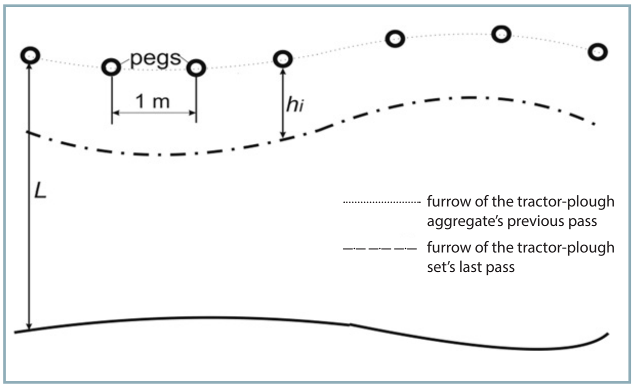

Fig. 4 Measuring scheme of the working width of tractor-plough aggregate

Fig. 5 Steel mouldboards with soil sticking

The fuel consumption was measured by means of a DFM-50C meter with 1% error margin.

Results and discussion

Typical soil type for southern Ukraine is sod-podzolic humus. Testing of the tractor-plough aggregate was carried out after winter wheat harvest. Stubble cleaning of this agricultural crop was completed a month before ploughing. The tillage depth was 5–7 cm. During the period since the stubble cleaning up to ploughing test, there was a rainfall of 10 mm. During the tractor-plough aggregate testing, winter wheat remnants and small weeds did not exceed 15 g·m^{-2}.

The soil bulk density arithmetic mean for the 0–25 cm layer was 1.21 g·cm^{-3} and the soil moisture equalled to 22.8%.

Considering the experimental conditions, wet soil was constantly being stuck to the plough steel mouldboards (Fig. 5). However, this phenomenon was not observed in terms of Tekrone mouldboards (Fig. 6).

Observation of the ploughs showed that, in case of soil sticking to the plough mouldboards, there occurs a "soil moves over soil" process, which always results in the plough draft resistance increase. Analysis of experimental data showed that utilization of the Tekrone mouldboards and landsides instead of steel ones facilitated a decrease in the

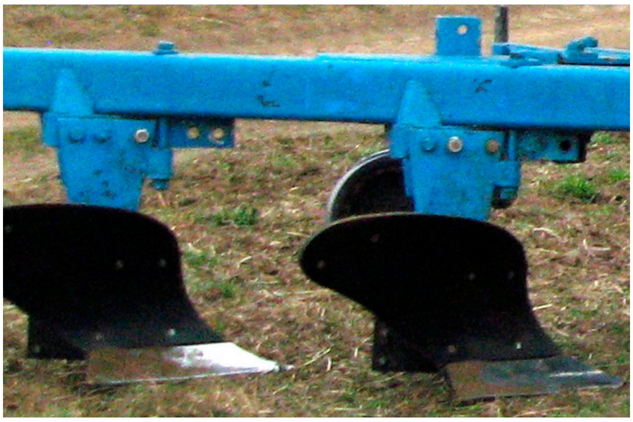

Fig. 6 Tekrone mouldboards without soil sticking

plough draft resistance. Consequently, if the plough draft resistance for the equipment made of steel 60 is 34.5 kN, it is 29.8 kN for the equipment made of Tekrone. The difference between the plough draft resistances was 4.7 kN, accounting to 13.6%. With the confidence level of 95%, it is possible to argue that this difference is significant, because it is larger than the least significant difference ($LSD_{0.5}$). In this case, the latter equals to 0.21 kN.

The draft resistance fluctuation variance of the plough with Tekrone mouldboards and landsides was equal to 6.40 kN^2; it was 8.7 kN^2 for the plough with steel equipment. However, this difference (i.e. 2.3 kN^2) is insignificant according to the *F*-test.

The variation coefficient of the draft resistance fluctuations for each plough did not exceed 9%. The plough average width of both tractor-plough aggregates was practically the same and equalled to 1.76 ±0.01 m.

In regard to the experimental data analysis, it was observed that the frequency spectrum of ploughing width oscillations was approximately the same for both tractor-plough aggregates (Fig. 7).

Therefore, the main part of the variances of these processes is concentrated in the frequency range 0–1 m^{-1}. The cut-off frequency for both normalized spectral densities was also approximately the same. The maximum of these functions took place at frequency 0.2 m^{-1}. Aforementioned observations indicate that the plough width indicators do not show any deterioration by replacing the steel mouldboards and landsides with equipment made of Tekrone.

The real ploughing depth of the plough with Tekrone equipment was changing within the 24.5 ±0.3 cm range (Table 2). The ploughing depth for the plough with steel equipment was changing within the 23.9 ±0.3 cm range.

As it is obvious from Table 2, the difference between ploughing widths is 0.6 cm, and least significant difference ($LSD_{0.5}$, cm) between these parameters is merely 0.4 cm. Consequently, the real ploughing depth of the plough with Tekrone equipment was greater.

The oscillation frequency of ploughing depth for both ploughs was estimated by normalized correlation functions of these processes. Their analysis showed (Fig. 8) that correlation length of the ploughing depth oscillations of the compared ploughs is almost the same and equals to approx. 0.9 m.

At the same time, the process of the ploughing depth oscillations produced by the plough with steel mouldboards and landsides showed a periodic component (Fig. 8). This function is described by the following equation:

$$R = \exp(-0.47X) \times (\cos 2X + 0.24 \sin 2X) \quad (2)$$

On the contrary, the process of the ploughing depth oscillations produced by the plough with Tekrone mouldboards and landsides did not show a periodic component and can be described as follows:

$$R = \exp(-2.05X) \times (\cos 2.5X + 0.82 \sin 2.5X) \quad (3)$$

The former is a more high-frequency process. The normalized spectral densities of the compared processes confirm this fact (Fig. 9).

The analysis of these figures showed that ploughing depth oscillation variance of the plough with steel mouldboards and landsides is distributed over a wider frequency range in contrast to the plough with Tekrone equipment. Simultaneously, in accordance with the *F*-test,

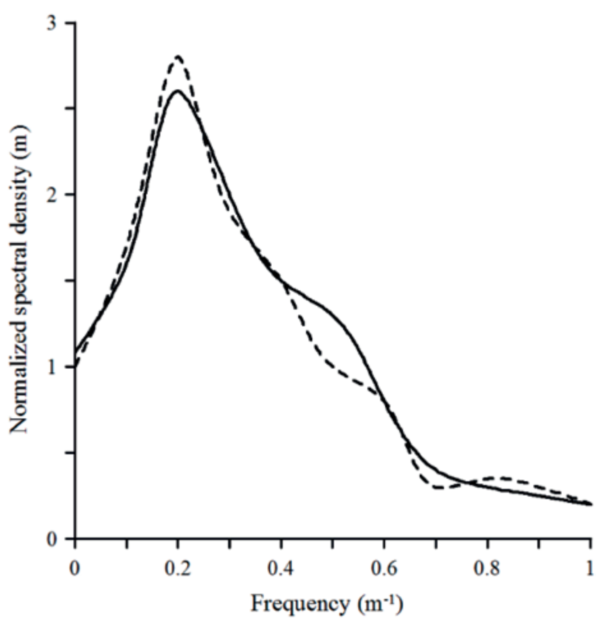

Fig. 7 Normalized spectral densities of the ploughing width oscillations of the ploughs with steel 60 (– – –) and Tekrone (—) equipments

Table 2 Statistical parameters of the ploughing depth

Parameter	Plough with mouldboards and landsides made of	
	Steel	Tekrone
Average (cm)	23.9	24.5
Confidence interval (95%, cm)	23.9 ±0.3	24.5 ±0.3
Variance (cm^2)	1.80	1.51
Standard deviation (±cm)	1.34	1.23
Coefficient of variation (%)	5.6	5.0
Least significant difference ($LSD_{0.5}$, cm)	0.4	

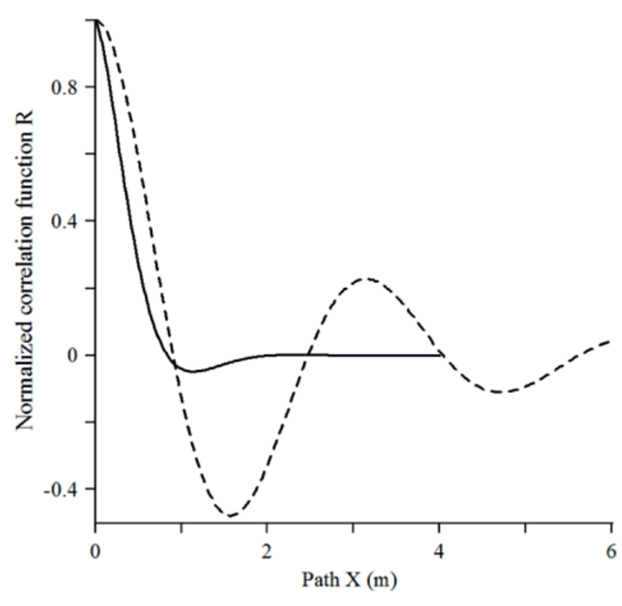

Fig. 8 Normalized correlation functions of oscillations of ploughing depth of the ploughs with steel (– – –) and Tekrone (—) equipments

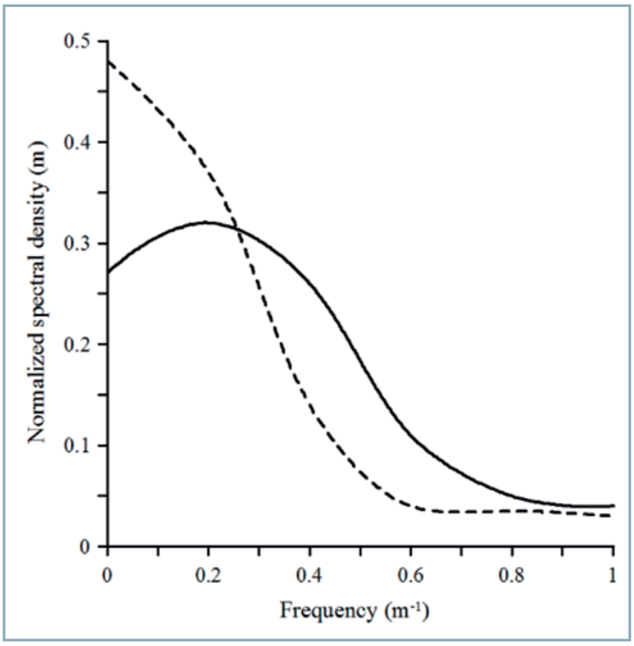

Fig. 9 Normalized spectral densities of ploughing depth oscillations of ploughs with steel (– – –) and Tekrone (—) equipments

both variances (1.80 cm^2 and 1.51 cm^2 – Table 2) represent the same random sample.

In Ukraine, the agrotechnical tolerance (Δ) of the ploughing depth oscillation equals to ±2 cm. Ploughing depth exit frequency beyond this agrotechnical tolerance can be calculated from the following formula (Panov, 2015):

$$\omega = \sqrt{\alpha^2 + \beta^2} \times \frac{1}{2\pi} \exp\left(\frac{-\Delta^2}{2D}\right) \quad (4)$$

where:

α, β – normalized spectral density approximation constants of the ploughing depth oscillations

D – variance of the ploughing depth oscillations

Considering the plough with steel mouldboards and landsides, α = 2.05, β = 2.5, and D = 1.80 cm^2. In this case, ω = 0.169 m^{-1} and the probability (P_{at}) of the maintaining agrotechnical tolerance Δ = ±2 cm amounts to 88%.

For plough with Tekrone mouldboards and landsides, α = 0.47, β = 2.0, and D = 1.45 cm^2. Consequently, ω = 0.084 m^{-1} and P_{at} = 93%.

On the basis of field results, the speed of the tractor-plough aggregate with plough Tekrone mouldboards and landsides was equal to 8.1 km·h^{-1}. The analogical quantity for the tractor-plough aggregate steel equipment was equal to 7.2 km·h^{-1}.

It is quite clear that such a positive difference in the work speed of the tractor-plough aggregate with Tekrone equipment results from its lower draft resistance. As a result, both tractor-plough aggregates have approximately the same plough width (1.76 m); however, they show different performance. Namely, the modernized tractor-plough aggregate was more productive in contrast to aggregate with traditional steel equipment – by 12.6% (1.43 ha·h^{-1} vs 1.27 ha·h^{-1}).

The fuel consumption of the tractor-plough aggregate with the steel mouldboards and landsides was equal to 22.86 l·h^{-1}. Simultaneously, the fuel consumption of the modernized tractor-plough aggregate was lower – 22.69 l·h^{-1}. In regards to this, fuel consumption per hectare of the aggregate with steel equipment was equal to 22.86/1.27 = 18.00 l·ha^{-1} fuel consumption per hectare of the aggregate with Tekrone equipment was 22.69/1.43 = 15.87 l·ha^{-1}.

Obviously, employment of the plough with Tekrone mouldboards and landsides instead of steel ones allowed the reduction of the specific fuel consumption by 11.8%.

Conclusion

Field experiment conducted showed that the Tekrone friction coefficient is 2.6 times lower in contrast to the friction coefficient of steel; Tekrone shows the prerequisites for employment of this composite material in the agricultural machinery, namely in production of the plough mouldboards and landsides.

The analysis of the experimental data showed that utilization of the plough with Tekrone equipment instead of steel one excludes sticking of the wet soil to it. Thereby, there occurs a process of "soil moves over plough mouldboard surface" instead of the "soil moves over soil" process.

The draft resistance of plough with Tekrone equipment decreased by 13.6%. Consequently, the performance of the novel tractor-plough aggregate increased by 12.6% and its specific fuel consumption decreased by 11.8%. At the ploughing depth (±2cm), the preserving probability of the agrotechnical tolerance increased from 88% to 93% for the plough with Tekrone equipment.

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