Tomasz STAWICKI
West Pomeranian University of Technology, Department of Agrotechnical Systems Engineering
ul. Papieża Pawła VI nr 1, 71-459 Szczecin, Poland
e-mail: tomasz.stawicki@zut.edu.pl

LIMIT WEAR OF WORKING PARTS OF SUBSOIL SHANKS WITH REGARD TO THEIR DESIGN SOLUTIONS

Summary

The report presents results of a 3D study of the contour and angles of subsoil shanks changes which develop due to wear caused by the soil during the ground cultivation. The results of 3D imaging were subject to the analysis aimed at the identification of the limit wear of the parts concerned. Significant differences were found in changes in the contour and angles of blades with regard to the design variants. The results of the study can indicate a need of further operation research to verify the suitability of certain variants of the blades exhibiting differences in terms of material and design

Key words*: blades, field study, abrasive wear, contour and angles, 3D study*

STAN GRANICZNEGO ZUŻYCIA ELEMENTÓW ROBOCZYCH GŁĘBOSZA A ICH ROZWIĄZANIE KONSTRUKCYJNE

Streszczenie

Przedstawiono wyniki badań 3D stanu geometrii dłut głębosza, który konstytuował się w następstwie zużyciowego oddziaływania gleby w warunkach uprawy polowej. Wyniki obrazowania 3D poddano analizie ukierunkowanej na identyfikację granicznego stanu zużycia badanych elementów. Stwierdzono, że występują istotne różnice w wywoływanych zużyciem zmianach geometrii dłut w zależności od ich wariantu konstrukcyjnego. Uzyskane wyniki badań stanowią przesłankę do wnioskowania o potrzebie realizacji badań eksploatacyjnych, jako niezbędnych dla weryfikacji przydatności użytkowej wariantów dłut głębosza, wykazujących różnice materiałowo-konstrukcyjne.

Słowa kluczowe*: dłuta głębosza, badania polowe, zużycie ścierne, stan geometrii, badania 3D*

1. Introduction

Parts of agricultural machinery and tools which operate in the soil have to be periodically replaced. Their operation suitability worsens due to changes in the contour and angles caused by the wear action of the soil and was manifested by, inter alia, loss of material that could affect the wear of a holder and ultimately decrease the quality of soil cultivation quality. In this connection it seems reasonable to identify criteria for the evaluation of the limit wear of operating parts which would make it possible to assess their operation suitability.

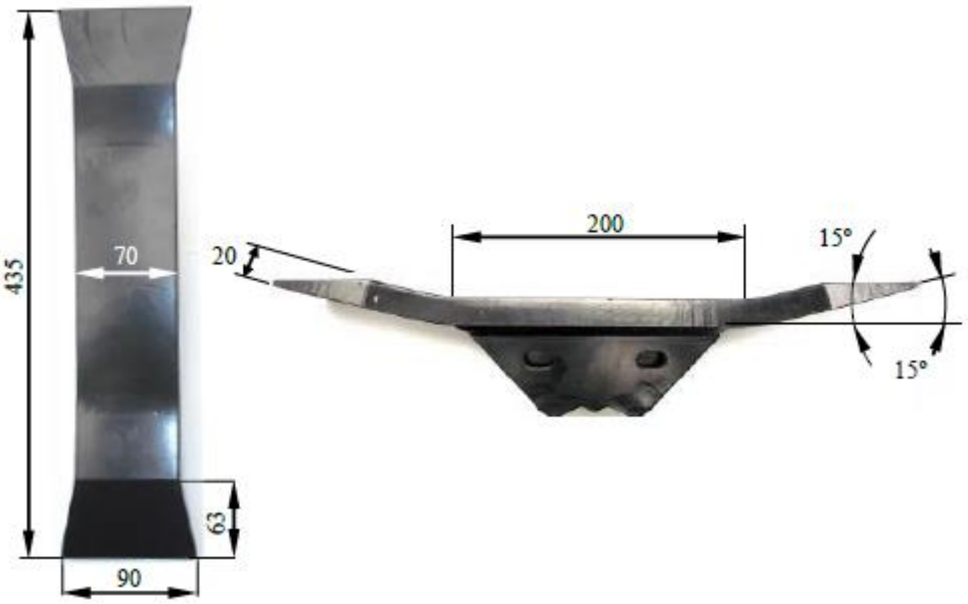
It shall, however, be noted that adopting the limit wear as a replacement criterion not necessarily corresponds to the optimum maintenance period due to farming production reasons (tillage timing preferences with regard to the optimum conditions). Undoubtedly, such a situation can happen in case of machines provided with several working parts. This is confirmed by the field research where cultivator points situated in the first row have shown more excessive wear compared to the ones in the second and third rows [14]. Interestingly, the operation research on a plow (7-furrow reversible plow) showed significant differences in the wear rate of shares; although operating conditions concerning certain plow bodies [16].

To clearly determine the limit wear of parts working in the soil might be useful to optimize the durability. It shall be noted, however, that manufacturers of genuine and spare parts do not determine the limit wear and decisions on replacement to be taken by users. This might be caused by determinants of intensity of the wear of working parts and tillage implements, in particular soils conditions (graining, volumetric density, stone percentage, humidity and pH), tillage parameters (speed and depth) and geometry of the parts operating in the soil which is referred to in numerous publications [1, 2, 4, 6, 9, 12, 13, 15]. The above mentioned conditions impede determining the durability of the working parts adequate for all operating conditions in particular through expressing the said durability by a measure of the work performed, e.g. cultivated area, working time or the friction distance covered. In this connection, the users of the farming machinery and tools have to follow their own experience and perform the visual inspection while making a decision on the replacement of the parts. They also pay attention to the change of dimensions and assess its influence on the further operation, and in particular on the agrotechnical quality of the tillage.

As far as the operating conditions for the farming machinery and tools are concerned it can be noted that the technological progress regarding their improvement at the same time causes new problems and challenges. Then users have to cope with an issue of choosing the available parts of several design and material variants that have not always been experimentally tested to be suitable for use. The practically known and experimentally evaluated strengthening technologies applied to parts exposed to the abrasive wear is pad welding with alloys of better anti-wear properties than a base material [5, 10, 17]. The application of plates made of sintered carbides [8, 11], is one of potentially promising and recently developed methods and the plates exhibit high abrasive wear resistance and are placed in areas that are most exposed to the destructive action of the soil friction matter. The above mentioned solutions can be combined in design-material solutions of the working parts of one machine or a cultivation implement. The purpose of this paper is a comparative analysis of the wear of different design blades aimed at determining the limit wear to qualify the parts under study for the replacement.

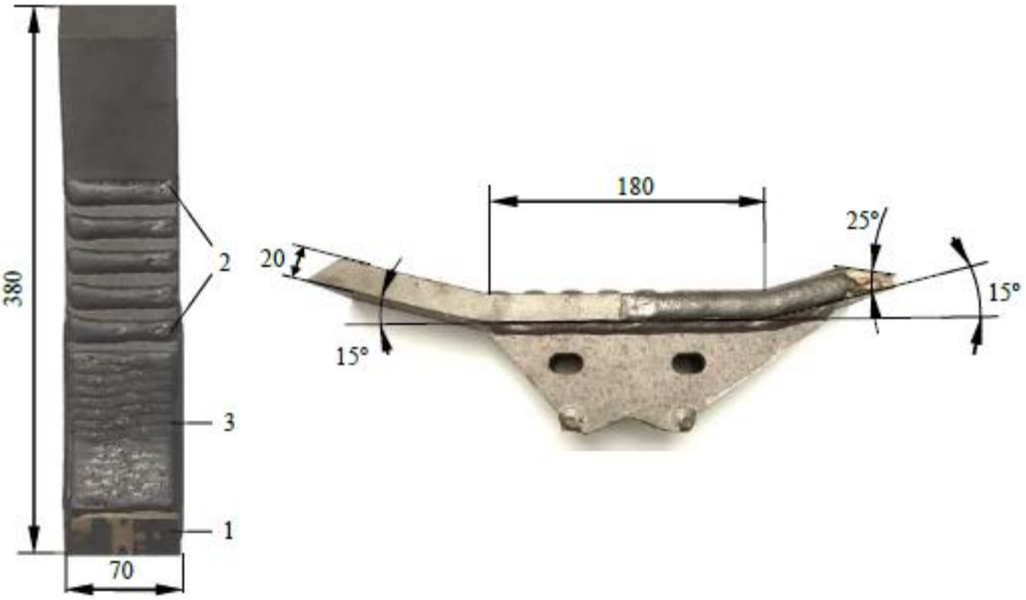
2. Materials and methods

The shanks subject to examinations were designed for subsoilers type Terraland TO 6000, used for the tillage in 2015 on fields of a farm located in West Pomerania. Three design variants of the shanks were examined, and they were designated A, B, C, respectively, for the purpose of this paper. Shanks type A were of simple design and made of homogeneous material (Fig. 1). Shanks type B (Fig. 2) and C (Fig. 3), were provided with sintered carbide plates and were pad welded in areas that were most exposed to the abrasive action of the soil. In the time of the experiment shanks A and B were available on the market, whereas shank type C was a prototype unavailable and not for sale. Table 1 gives chemical composition and hardness of steels used for the base parts of the shanks (flat bars), padding weld materials and sintered carbides.



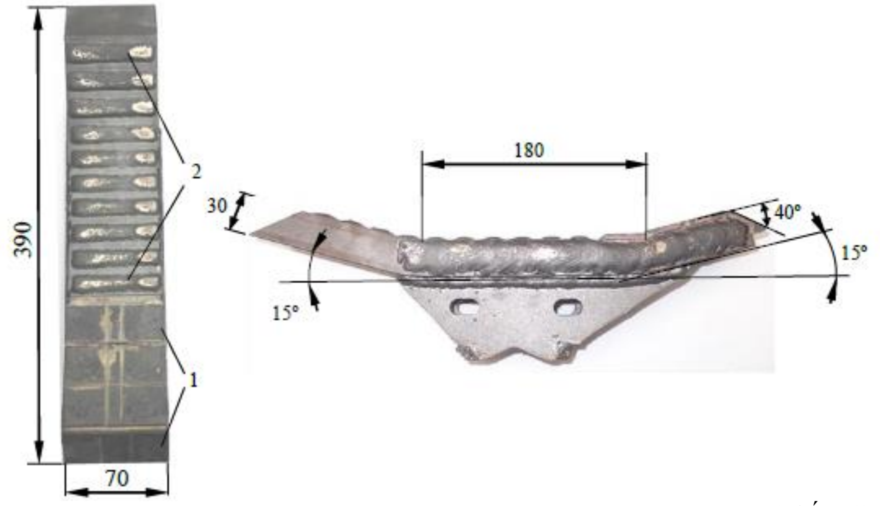
Source: own work / Źródło: opracowanie własne

Fig. 1. Main dimensions, shank A (homogeneous material blade)
Rys. 1. Podstawowe wymiary badanego dłuta, wariant konstrukcyjny A (dłuto jednorodne materiałowo)



Source: own work / Źródło: opracowanie własne

Fig. 2. Main dimensions, shank B: 1 – sintered carbide plates (5 mm thick), 2 – pad welded strips (ca 3 mm thick), 3 – padded weld surface (ca 3 mm thick)
Rys. 2. Podstawowe wymiary badanego dłuta, wariant konstrukcyjny B: 1 – płytki ze spieku węglików (grubość 5 mm), 2 – napoina pasmowa (grubość ok. 3 mm), 3 – napoina powierzchniowa (grubość ok. 3 mm)



Source: own work / Źródło: opracowanie własne

Fig. 3. Main dimensions, shank C: 1 – sintered carbide plates (5 mm thick), 2 – pad welded strips (ca 3 mm thick),
Rys. 2. Podstawowe wymiary badanego dłuta, wariant konstrukcyjny D: 1 – płytki ze spieku węglików (grubość 5 mm), 2 – napoina powierzchniowa (grubość ok. 3 mm)

Table 1. Chemical composition and hardness of shank materials
Tab. 1. Skład chemiczny i twardość materiału badanych dłut

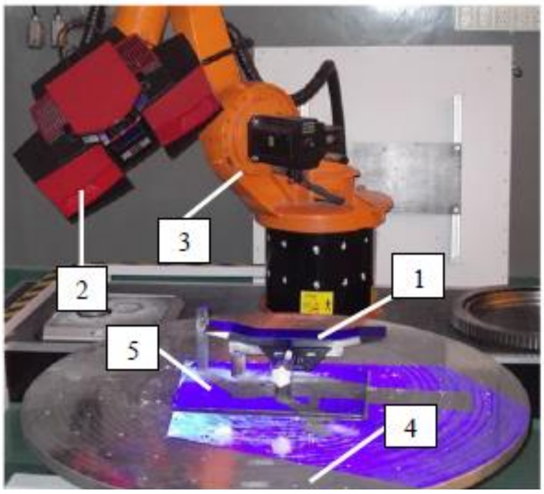
Element	Element concentration [%]; shank:			
	A	B and C	B and C	
	base material (steel flat bar)		padding weld material	sintered carbides
C	0.217	0.421	1.330	13.200
Mn	1.180	0.748	0.597	0.014
Si	0.287	0.246	0.643	0.252
P	0.009	0.019	0.011	0
S	0	0.004	0.012	0.254
Cr	0.319	0.090	6.365	0.052
Ni	0.068	0.096	0.082	0.265
Mo	0.027	0.028	0.020	0.601
V	0.017	0.003	0.018	0.573
Co	0.052	0.046	0.014	12.800
W	-	-	0.022	68.600
N	-	-	0	0.345
Fe	-	-	90.400	1.810
Hardness, HV	380.9 s=3.0	265.2 s= 0.9	993.7 s=0.1	1202 s=38

s – standard deviation

Source: own work / Źródło: opracowanie własne

The field study covered tests carried on fields after cereal harvest following the disk harrowing cultivation. The study continued for several days in changing soil and subsoiler operation conditions. The cultivation speed varied within the range of 2.26-2.56 m·s^1, and the depth from approx. 37 to almost 47 cm. The humidity of soil was determined by the drying and weighing method on samples taken from three soil layers, at the depth of 5-15, 15-30 and 30-45 cm accordingly – the humidity varied as follows: 10.7-14.0, 9.6-10.6 and 7.6-7.7%$_{\text{weight}}$. On the basis of the available soil map it was assumed that light loam, light silty loam and heavy loamy sand dominated. It shall be noted, however, the more detailed description of materials used for shanks and more complete specification of soil and cultivation conditions can be found in publication [7] that was aimed at the assessment of the resistance of the parts under study. This paper focuses on the evaluation of the shank geometry state which resulted out of the destructive action of the soil until dismantling the certain parts. The aim was to determine whether the change in the geometry caused by the wear of the parts depends on the design variant and to identify parameters describing the geometrical changes in shanks in terms of their suitability for determining the limit wear.

Changes in the geometry of the parts were evaluated by optical scanner Atos Triple Scan of GOM, installed on an industrial robot integrated with a turning table (Fig. 4). Shanks under study were fixed in a clamp to provide repeatable positioning. A head of the scanner was equipped with a structural light projector and 2-camera optical system to scan the surface of the parts. The measurement system of the camera provided the repeatability of 3D imaging with accuracy of 7 μm minimum. ATOS Professional V8.0. software was used for data processing.



Source: own work / Źródło: opracowanie własne

Fig. 4. Shank geometry test stand: 1 – part under study, 2 – scanner Atos Triple Scan, 3 – robot arm, 4 – turning table, 5 – blade clamp
Rys. 4. Stanowisko pomiarowe zmian geometrii dłut: 1 – badany element, 2 – skaner Atos Triple Scan, 3 – ramię robota, 4 – stół obrotowy, 5 – uchwyt do zamocowania badanych dłut

Shanks were scanned twice, i.e. before and after the operation in the soil. The mass wear of shank material was assessed along the longitudinal section (change in the length along the axis of symmetry), and mass wear in the face area (surface perpendicular with regard to cultivation direction) and flank area (side surfaces of a blade). The comparative analysis of the shank geometry changes on the cross-section perpendicular to the longitudinal axis of the parts and located in the middle of their length was carried out as well. Matlab software was used to determine the relative mass wear of the shanks on the cross-section concerned.

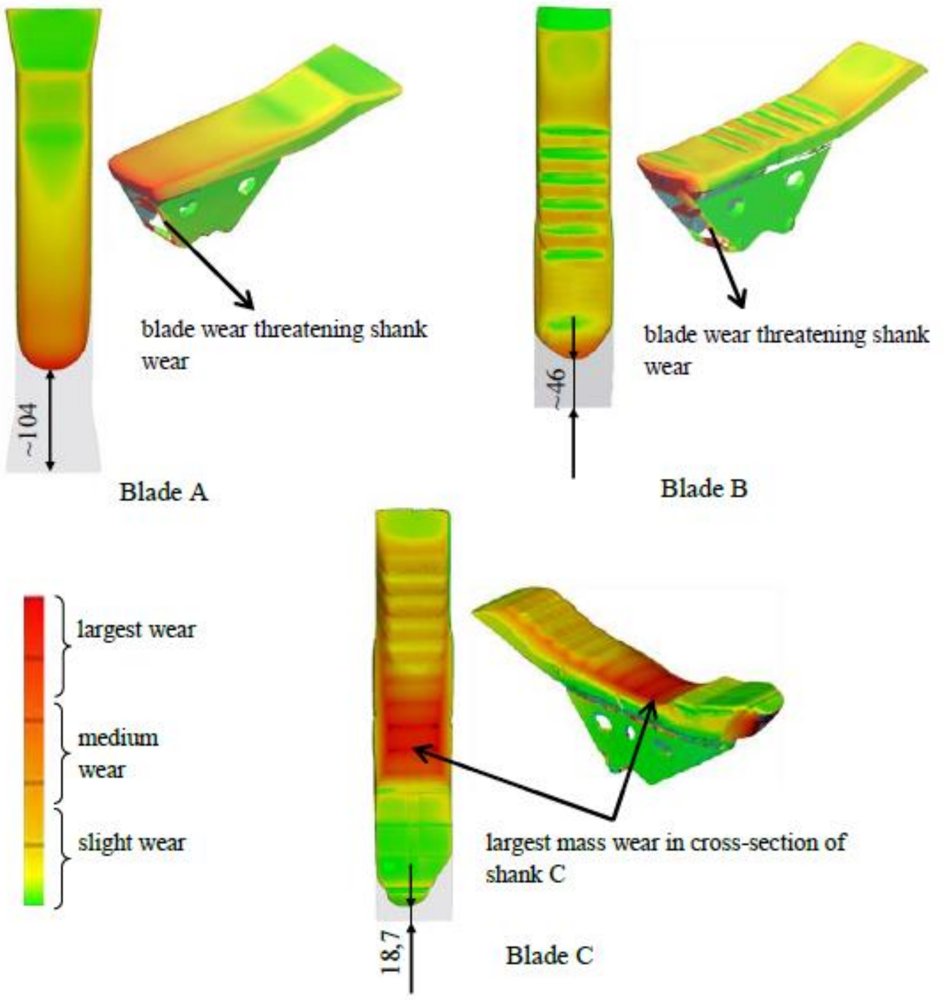
Thirteen shanks A comprising the complete set on the subsoiler and 11 shanks B and 2 prototype shanks C attached to make a complete set of working parts of the Terraland TO 6000 as well were subject to the field study. During the operation one shank C was lost due to broken holding down bolts and therefore two shanks B were excessively worn. Consequently, the laboratory tests with use of a 3D scanner covered 13 shanks A, 9 shanks B and one shank C.

3. Results and discussion

The comparative analysis of 3G images shows differences in the wear of the shanks according to the design variants. Fig. 4 shows selected representative results of measurements taken by the Atos Triple Scan. As far as shanks A are concerned, the wear mainly manifested itself by change in the length of the parts (Fig. 4). The length decrease of approx. 104.00 mm on shanks A (measurement along the longitudinal axis) threatened the wear of the beam holding the shanks. It means that change in the length of the parts A limits their operation usability.

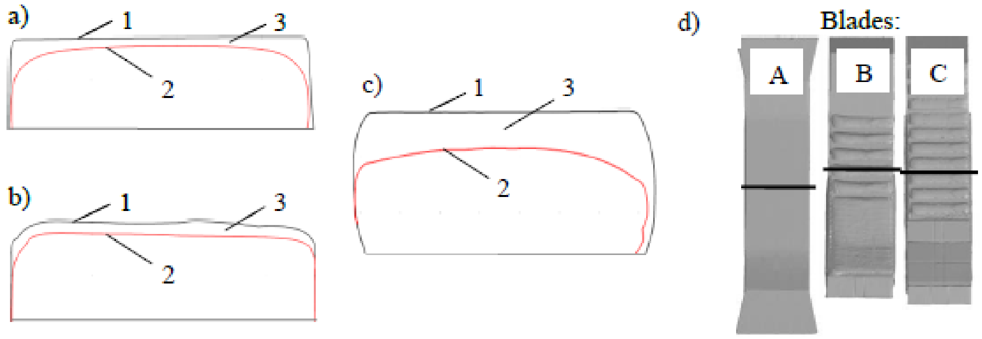
Although the design of shanks B is quite different, their operation usability, similarly to shanks A, is determined by change in the length. The change in the length was a result of the spalling of sintered carbide plates used to reinforce the shanks. The probable cause of the occurrence concerned was discussed in detail in a report on the intensity of wear and durability of the shanks under study [7]. The analysis of 3D imaging of shanks B showed that the linear wear of approx. 46 mm could have affected the wear of the beam (Fig. 5).

As far as shanks C are concerned, the largest mass wear was found in the central zone, and was explained by a significantly different state of the geometry since the change in the length was relatively small. It shall be noted, however, that the shank in question was dismantled not due to the change in its length, but because of the major mass wear in the pad-welded zone (an area with sintered carbide plates). The further use of shank C was aborted due to a risk of emergency wear, i.e. part being broken thus destroying research material.



Source: own work / Źródło: opracowanie własne

Fig. 5. Change to geometry of shanks A, B and C caused by abrasive action of soil (contour of new shanks shown grey)
Rys. 5. Zmiana geometrii elementów typu A, B i C wywołana zużyciowym oddziaływaniem gleby (kolorem szarym zobrazowano zarys dłut nowych)



Source: own work / Źródło: opracowanie własne

Fig. 6. Cross section: geometry of selected parts: a, b and c – contours of new and worn parts, blades A, B and C in adopted measurement cross-section, d – location of measurement cross-section 1 – new part contour, 2 – worn part contour, 3 – material damage

Rys. 6. Geometria wybranych elementów w przekroju poprzecznym: a, b i c – odpowiednio kontury elementów nowych i zużytych typu A, B i C w przyjętym przekroju pomiarowym, d – usytuowanie przekroju poprzecznego; 1 – kontur elementu nowego, 2 – kontur elementu zużytego, 3 – ubytek materiału

Fig. 6 presents results of measurements of the shanks of certain design that show changes in the geometrical dimensions over the cross-section. The cross-section where changes in the geometry of shanks A, B and C were assessed, was situated in the middle of the length of the parts (Fig. 6d), which corresponded to spots of similar load (cross-sections located at the same depth with regard to the surface of a cultivated field). According to the methodology assumptions, cross-sections of the shanks were subject to the further analysis by means of Matlab software to determine the percentage mass wear caused by the abrasion. In each case the calculations consisted in determining the difference between the area of the cross-section of a new part (Fig. 6 – black line (1) delineation) and the worn one (Fig. 2 – red line (2) delineation) and the reference of the calculated difference to the area of the new part

It was found that the percentage mass wear over the reference cross-section of the shanks varied within the following ranges: 8.9÷16.6% and 10.8÷15.6%, shanks A and B, accordingly. In case of shank C the mass wear over the same cross-section was 28.0%, and the largest wear of 33.7% was found elsewhere, (Fig. 6 – 3b). The analysis of the cross-sections showed that prior to the dismantling of the parts the width thereof had not changed significantly. Over the cross-section concerned, the change in the width of shanks A was 1.51 mm, shanks B only 0.125 mm and shanks C 7.01 mm respectively. Such a situation seems to be favorable with regard to the cultivation the quality of which was, to a greater extent, determined by the change in the length of the parts, in particular in case of shanks A and B.

4. Conclusions

The research results made a basis for drawing the following conclusions:

– operation usability of shanks A depended on changes in their length and the wear about 104 mm made the beam wear very likely; shanks A were the longest ones and had the largest wear allowance, thus it might be said that changes in geometry of shanks A followed the design assumption (basic engineering),

– changes in geometry of shanks B revealed the weakness of the said design; the shanks, although provided with tips strengthened and improved with sintered carbide plates, exhibited the limit wear due to the length decrease (longitudinal wear) of some 46 mm, and at the same time rather small wear was observed on pad-welded spots (Fig. 3 – b1, b2); the above shows the insufficient protection of shanks B against the change in the length which consequently showed as ineffective use of the pad-welded material which was used to reinforce areas of the parts that were exposed to intensive abrasion,

– analysis of the geometry of shank C made a basis for concluding on the effectiveness of the application of sintered carbide plates, and in case of the design solution concerned the wear of the most loaded area of the blade was reduced (minor change in the length and thickness of sintered carbide plates), consequently the change in the blade length did not impost the replacement thereof; the largest mass wear of shank C material was shown behind the sintered carbide plates, where the maximum mass wear over the cross-section was 31.7%; the state of shank C geometry makes the breakage believable.

The results of 3D imaging clearly show differences in the wear process of subsoiler shanks with regard to their design variants. The differences also concern the parts of the similar design solutions regarding the strengthening thereof (shanks B and C). The above means the great uncertainty of predicting the durability of the parts in question only on the basis of evaluating the material-design solutions. It also confirms that the further field research is necessary for determining the limit wear and verifying the operation usability of the parts under study.

5. References

[1] Fielke J.M.: Interactions of the Cutting Edge of Tillage Implements with Soil. Journal of Agricultural Engineering Research, 1996, 63, 61-72.

[2] Frid M., Sabatka J., Celjak I.: Vliv pracovnich podminek na vybrane parametry sipovych redlicek. Res. Agricult. Eng. - Zemed. Tech, 2004, 50, 2, 66-74.

[3] Horvat Z., Filipovicb D., Kosuticb S., Emert R.: Reduction of mouldboard plough share wear by a combination technique of hardfacing. Tribology International, 2008, 41, 778-782.

[4] Hamblin M.G., Stachowiak G.W.: Description of abrasive particle shape and its relation to two-body abrasive wear. Tribology Transactions, 1996, 39, 803-810.

[5] Horvat Z., Filipovicb D., Kosuticb S., Emert R.: Reduction of mouldboard plough share wear by a combination technique of hardfacing. Tribology International, 2008, 41, 778–782.

[6] Kostencki P., Nowowiejski R.: Wytrzymałość ścierna wybranych lemieszy płużnych podczas uprawy pyłu zwykłego o dwóch stanach nawilgocenia. Tribologia, 2006, 2, 123-142.

[7] Kostencki P., Stawicki T., Białobrzeska B.: Durability and wear geometry of subsoiler shanks provided with sintered carbide plates. Tribology International, 2016, 104, 19-35.

[8] Müller M., Chotěborský R., Valášek P., Hloch S.: Unusual possibility of wear resistance increase research in the sphere of soil cultivation. Tehnički Vjesnik, 2013, 20, 4, 641-646.

[9] Napiórkowski J.: Zużyciowe oddziaływanie gleby na elementy robocze narzędzi rolniczych. Inżynieria Rolnicza, 2005, 12 (72), 3-171.

[10] Napiórkowski J., Kołakowski K.: Wpływ rodzaju warstwy wierzchniej na przebieg zużywania dłut lemieszy płużnych. Inżynieria Rolnicza, 2010, 4 (122), 171-178.

[11] Napiórkowski J., Ligier K., Pękalski G.: Właściwości tribologiczne węglików spiekanych w glebowej masie ściernej. Tribologia, 2014, 2, 123-134.

[12] Natsis A., Papadakis G., Pitsilis. J.: The Influence of Soil Type, Soil Water and Share Sharpness of a Mouldboard Plough on Energy Consumption, Rate of Work and Tillage Quality. Journal of Agricultural Engineering Research, 1999, 72, 171-176.

[13] Natsis A., Petropoulos G., Pandazaras C.: Influence of local soil conditions on mouldboard ploughshare abrasive wear. Tribology International, 2008, 41, 151-157.

[14] Owsiak Z.: Zużycie redliczek kultywatora w glebie gliniastej. Zesz. Problem. Postęp. Nauk Rolniczych, 1996, 144, 141-146.

[15] Stabryła J.: Research on the degradation process of agricultural tools in soil. Problemy Eksploatacji, 2007, 4, 223-232.

[16] Stawicki T., Białobrzeska B, Kostencki P.: Tribological properties of plough shares made of pearlitic and martensitic steels. Metals, 2017, 7, 139: 1-20.

[17] Bayhan Y.: Reduction of wear via hardfacing of chisel ploughshare. Tribology International, 2006, 39, 570-574.