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Research of strengthening plough parts by welding

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1. Introduction

Service cost of agricultural machines depends on working conditions, downtime, maintenance and repair expenses. Their reliability is increased using special materials, multilayer steels, structural solutions and special means of their elements manufacture and applying welding (more seldom spraying) with hard layers [1, 2]. The parts of agricultural machines suffering the greatest wear are plough points and ploughshares. When they thin – they break, when they shrink– they do not fulfill depth (agricultural) requirements. To retard their wear, manual arc welding by electrodes is used [1-4].

In the ground (abrasive medium) harder alloyed steels, with higher carbon content, wear down slower. Relatively cheap and resistant to wear are medium carbon, boron micro-alloyed hardened steels. In EU states these steels are generally used for manufacture of the elements of agricultural machines (Lubor 044, 38MnB5, Hardox steels [5, 6]), while in ICS carbon special (spring, ploughshare) grade 65G, L53, L56 steels [2-4, 7, 8] are popular. Alloyed steels are not used in agriculture because of their high price.

Hardness of an element depends on its structure, e.g. 5 mm thick disks are made of 40-45 HRC hardness, rather seldom up to 49-54 HRC (for its brittleness), hardness of 11 mm thick disks is 50-54 HRC. To increase wear resistance the working surfaces of the elements are arc welded with the layers of 2-3 mm thickness and 55-66 HRC hardness [1, 2]. The surfaces can be cemented, boroned [9-11]. At the most intensive wear spots hard alloys may be inserted.

In Germany at manufacture and repair the working surfaces of machine elements are either welded or sprayed with hard layers [10, 11]. In the work [12] it is determined that welding of layers alloyed with graphite and boron carbide improves resistance to abrasive wear.

The surfaces of agricultural machine elements are strengthened in two ways. Their front surface is welded if they work in sand ground, their rear surface - if they work in heavy – clay ground [2, 10, 11]. These research results show that by controlling the thickness of both the machine element and the welded layer adequate strength to wear ratio is achieved self whetting effect is obtained in any abrasive ground. It cannot be practically implemented because a number of factors affecting the wear, such as humidity, composition, etc. are uncontrollable. For this reason a more simple technique should be applied for the problem solution what welding material and on which surface is to be applied to prolong service life of the elements.

Resistance to abrasive wear of hard layers has been analyzed by M.M. Khruschiov et al. [1-3]. Therefore when using ICS technologies and materials the wear rate of welded elements can be predicted. In Lithuania only the electrode T-590 from the electrodes made in ICS is used and it is not universal.

In welded surfaces the concentrations of 35% chromium, 5% carbon, 7% tungsten, 9% niobium and other elements can be obtained [2, 3, 5, 6]. If welding two hard layers than the chemical composition of the latest one is equal to pure welded metal. However because of limited thickness of the welded element, usually it is possible to make just one layer on the wearing surface [13].

In laboratory research V. Jankauskas [14] has determined that a welded surface subjected to low abrasive pressure wears 9.7 times slower compared to the wear of boron micro-alloyed steel used for plough points (Fig. 1). This fact makes implementation of the research results expedient.

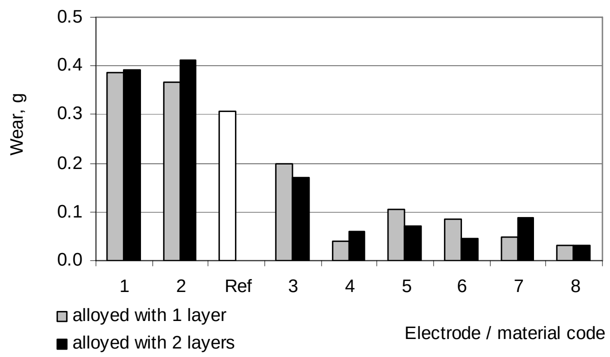

Fig. 1 Wear of alloyed layers in ASTM G65 investigation (F = 130 N, t = 1200 s; S = 2880 m) [14]. Materials: *Ref* – LUBOR 044; *1, 2* - (Fe-C-Cr-Si) layers with low carbon and chromium content; *3, 4* – (Fe-C-Cr-Si) layers with high carbon and chromium content; *5, 6* – (Fe-C-Cr-C-Si-B) layers abundantly alloyed with carbon, chromium, boron; *7, 8* – (Fe-C-Cr-Si-V-W-Mo-B) layers abundantly alloyed with chromium, niobium, molybdenum, tungsten etc.

The research objective is to analyze the wear of the elements in agricultural machinery (plough points, sugar beets digging ploughshares) arc welded with different hard layers under working conditions.

2. Testing procedures

For welding the plough points ESAB, Lincoln Electric electrodes were used [15], welding modes were selected according to the producer recommendations.

The wear of plough points Frank No 94610/96411 (ploughs MF 725-6AX and MF 715-4AX) welded with hard layers of different compositions was tested (Table) in L. Stonkuviene agrarservice company where heavy (clay) ground is prevailing (Vilkaviškis and Šakiai districts) in 2004 and 2005.

The front surface of plough points is welded with a hard layer of 50-65 mm length and 2-3 mm thickness (Fig. 2, a). The rear surfaces are welded by the layers of 45-55 mm length, 1.5-2.5 mm thickness in longitudinal seams (Fig. 2, b). The welded plough points were cooled in the ambient air [10, 11]. The welded front plough point surface covered 20-25 % surface area. Attempting to weld a greater surface area the plough point underwent visual deformation.

Table

Composition of welded layers

Nr.	Layer/electrode type	Chemical composition, %	Hardness, HRC
1	Low carbon and chromium content (Fe-C-Cr)	C-0.51; Si-0.63; Mn-1.18; Cr-4.75	62
2	High carbon and chromium content (Fe-C-Cr)	C-3.35; Si-0.5; Mn-1.06; Cr-26.45	64
3	High carbon chromium, silicon, boron content (Fe-C-Cr-Si-B)	C-3.45; Si-0.81; Mn-0.23; Cr-24.48; B-0.307	65
4	High carbon, chromium, niobium, molybdenum, tungsten content (Fe-C-Cr-Nb-Mo-W-B)	C-3.56; Si-3.0; Mn-0.19; Cr-22.24; W-3.58; Mo-7.75; Nb-6.83; B-0.084	68

Fig. 2 Welded surfaces and arrangement of seams a – front surface straight welded; b - rear surface lengthwise welded; c – rear surface lengthwise and one seam on the edge surface

Effectiveness of hard layers was tested by welding plough share edges of sugar beets digging harvesters Holmer Terra Dos. Tests were carried on in Sachsen-Alhalt land enterprises (Germany). New Holmer GmbH ploughshares with the layers of 3 and 4 types (3-5 mm thick) with welded edges were used.

Wear of the tested parts from agricultural machines was determined by weighing (scales SK 2001, accuracy 0.1 g) prior the testing and after the first break of a plough point. Wear value of the parts (shrinkage) was determined by callipers SC-3-400-0.1 (GOST 166-89).

The effect of welding to the change of forged steel hardness was determined by microhardometer PMT-3 (0.49 N). The polished cross-section was measured.

20 plough points were tested, 4 of them were standard (from a production line) (S). 16 plough points were welded by 4 different materials. 48 ploughshares were tested, 24 of them were welded. The rate of wear (mass and linear) was compared to the shrinkage and wear of standard ploughshares (S) (100%).

3. Results

Analyzing operation of the plough with a new (standard) and welded rear surface of its points it was found that the welded points broke first due to thinning. When testing the new points with welded front surface, it was determined that no welded points broke first because they withered due to wear.

Ploughs with welded rear surface points ploughed 45.5 hectares/per plough point (182 km for a plough point), those with welded front surface ploughed 62.3 h/point (249 km for a plough point).

Average mass of the tested points was 2226 g for new points, 1489 g for worn points (wear -33.1 %); average length: 277.3 mm for new points, 224.8 mm for worn to the critical limit.

Wear and shrinkage of plough points with welded rear and front surfaces are presented in Figs. 3 and 4, respectively.

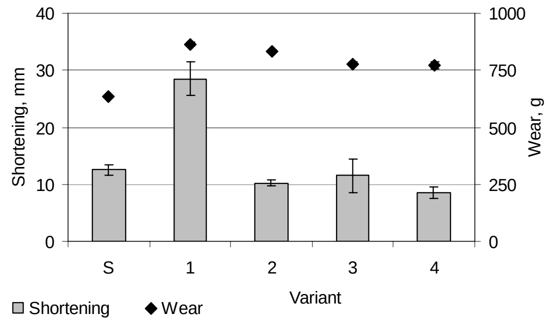

Fig. 3 Test results of plough points wear strengthened by welding rear surfaces

Plough points with welded rear surfaces were found to wear faster by 20 to 37 % than the control ones (Fig. 3). Therefore, it may be assumed that while welding metal hardness of the plough point rear surfaces decreases due to thermal effect and wear of welded front surfaces of the points is more intensive than that of standard points.

Length of the points changed differently. The first version points welded with the layer (Fe-C-Cr) were shrinking 2.08 times faster than the control ones, the third version (Fe-C-Cr-Si-B) were shrinking in the same way as the control ones. The second version points with welded (Fe-C-Cr) layer were shrinking 19 % slower and the fourth version with (Fe-C-Cr-Nb-Mo-W-B) layers – 38 % slower than the control ones. Slower shrinkage of the 2 and 4 versions of the points indicates that the welded layers can wear slower than the main steel of plough points.

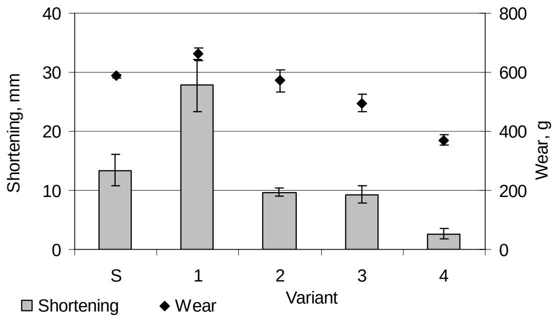

Fig. 4 Test results of new and strengthened by welded front surfaces plough points wear

Testing results analysis of the points with welded front surfaces (Fig. 4), shows an increase in wear in the surface welded with the first version (Fe-C-Cr) layers. During testing that layer was worn completely. Wear of the other layers slowed up to 35 %. The composition of front surfaces materials of the points is different. With the materials of different strength to wear, therefore to make decision on materials effectiveness by means of a mass criterion was impossible.

The welded plough points were cooled in air for reducing inner stresses of hardened steel (to preserve strength of a part), however, steel hardness (and strength to wear) might be expected to decrease [1, 2]. To evaluate that process microhardness of a cross-section of the welded and new points was measured (Fig. 5).

Hardness of nonwelded points at cross-sections was found to be from 4000 to 4100 MPa, hardness of the welded plough points had reduced up to 2700-3000 MPa due to the thermal effect. For this reason the wear front surfaces of the points front surfaces intensified – when working they got thinner. Hardness of the front (working) surface increased (the wear slowed down) when it had worn 6-8 mm, when the welding zone of a hard layer and the plough point steel was reached during the wear process.

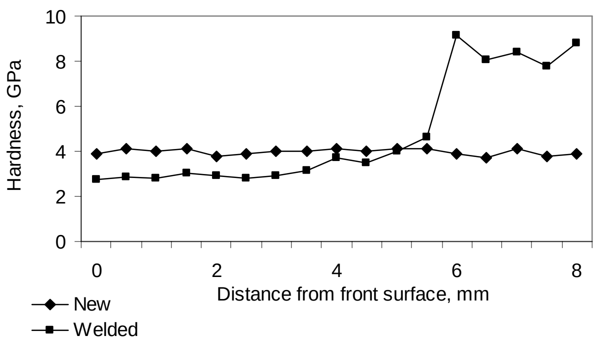

Fig. 5 Hardness variation in cross section of the welded (electrode 3) and new plough points

Variation of longitudinal cross-sections of plough points with standard welded rear and front surfaces after 40 ha ploughing is presented in Fig. 6. Standard points and the ones with low carbon and chromium content shrink faster (Figs. 3-4).

The plough points with alloyed rear surfaces wear in their thinning points and in the front surfaces welding seams show through while the hard layers, having lost the carrying layer, crumble (Fig. 7, b). Thus, it can be stated that welding of the rear surfaces intensifies wear of the front surfaces of the points and it is irrelevant even under heavy ground conditions (low abrasiveness).

With a plough point wear the cutting edge width (touching the bottom of a furrow) depending on plough point thickness changes. The cutting edge of new points is 16-17 mm width (Fig. 7, a). Cutting edge width of the points with welded rear surface depends on hard layer thickness which reduces up to 3-6 mm with the point wear (Fig. 7, b), while that with the welded front surface has the rear surface of 25 mm width due to the thickness of a plough point (Fig. 7, c). The width up to 4-5 mm is considered to be optimal warranting the steady plough digging depth [15].

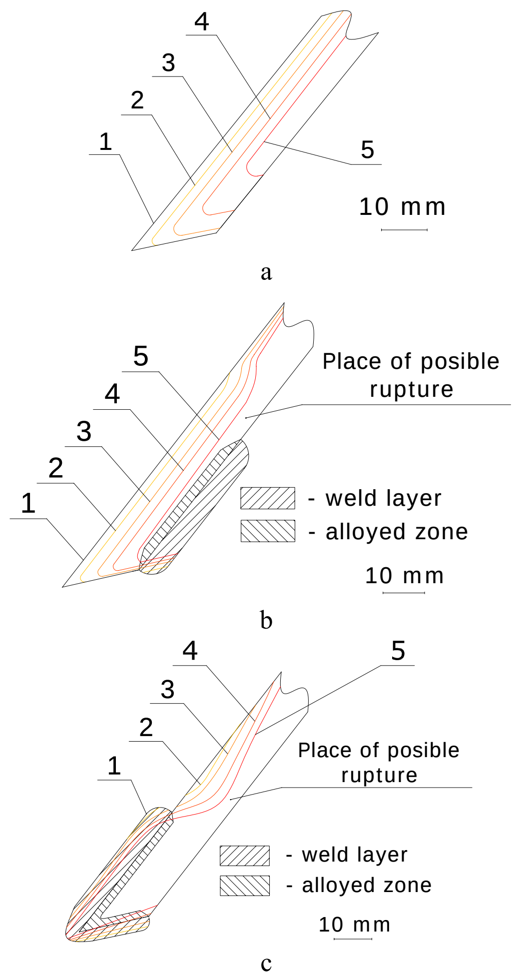

Fig. 6 Plough points: a – standard, b – with welded rear, c – with welded front surface their longitudinal cross-sections: *1* – side-view of a new or welded point, *2* – after ploughing of 10 hectares, *3* – 20 ha, *4* – 30 ha, *5* – 50 ha

To weld the front surfaces of plough points, Fe-C-Si-Cr-B and Fe-C-Cr-Nb-Mo-W-B layers are the most efficient in reducing the point wear and its mass, by 18 % and 35 %, respectively (Fig. 4). Plough point shrinkage is reduced 6 times by the layers of the 4th type – (Fe-C-Cr-Nb-Mo-W-B). A great difference between the points wear and shrinkage is caused by maximal variation of the wear spot. When working with nonalloyed points, their front surface close to the cutting edge undergoes the highest wear, whereas in plough points with the welded front surface its front surface behind the hard layer and not its point or hard layer undergoes the most intensive wear (Figs. 6, c and 8). This proves that minimal wear (maximal life) of plough points can be achieved by welding their largest possible front surface area, though manual arc welding cannot be applied because of great plough point deformations.

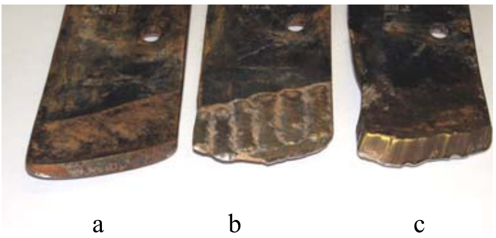

Fig. 7 Plough point rear surfaces after production tests: a – nonwelded, b – with welded rear surface, c – with welded front surface

Efficiency of welded layers can be evaluated only by the difference of shrinking of the new and welded front surface plough points under working conditions.

Fig. 8 Front surface welded with high content of carbon and chromium Fe-C-Cr-Si (a) and high content of carbon, chromium, silicon and boron Fe-C-Cr-Si-B (b) hard layers

The reliable value of wear difference of sugar-beet digging harvesters ploughshares (standard and standard with cutting edges welded with hard layers) when they reach the marginal wear value according to the width (35 mm) has not been determined due to negligible variation of the front surface area.

Ground characteristics had a different effect on the wear rate, the marginal wear value (35 mm) when the harvester has worked from 61 to 187 hectares (from 5.1 to 15.6 hectare or 20.3 to 52 km working path for a ploughshare). Average mass of the tested plough points is: 2330 g for new, 1812 g for worn points (wear 19-25 %).

Different working conditions may stipulate different thinning up to three times of plough points (width wear). However, this width wear of ploughshares is different. Linear wear of new ploughshares is directly proportional to production when a constant digging depth is maintained by machine (Fig. 9). Ploughshares with the welded cutting edges wear slower up till the welded layer wears. Afterwards the wear rate of standard and welded ploughshares (working in a pair) becomes uniform, but with an increase in production the effect of higher loads of broader ploughshares (greater digging depth) becomes evident. For this reason the wear of alloyed ploughshares is more intensive and approaching the marginal state the wear may be uniform.

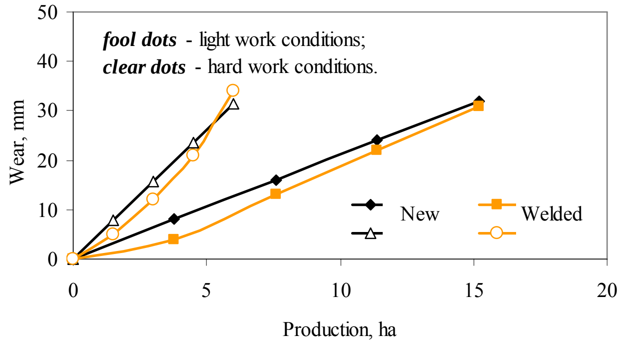

Fig. 9 Effect of production on ploughshares wear (electrode 4)

4. Conclusions

1. Strengthening of working elements of agricultural machines by welding their rear surfaces is inexpedient since it intensifies the wear of front surface because of reduced hardness of hardened steel caused by thermal welding effect;

2. The welded front surfaces of plough points wear slower when coated with Fe-C-Cr-Si-B or Fe-C-Cr-Nb-Mo-W-B layers; Fe-C-Cr-Nb-Mo-W-B hard layers reduce the wear rate up to 6 times;

3. To achieve the maximal life of working parts, their front surface welded area must be as large as possible;

4. Welding of a cutting edge by hard layers does not increase the life of an agricultural machine element.

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APVIRINTŲ PLŪGO DETALIŲ DILIMO TYRIMAI

R e z i u m ė

Pateikti apvirintų kaltų dilimo gamybinėmis sąlygomis tyrimų rezultatai. Nustatyta, kad kaltai, kurių priekinis paviršius apvirintas, dyla lėčiau už neapvirintus. Apvirinant kaltų užpakalinį paviršių, dėl elektros lanko šiluminio poveikio sumažėja metalo kietis, todėl šie kaltai dyla sparčiau už neapvirintus. Dėl to apvirinti kaltų užpakalinį paviršių netikslinga. Kaltai, kurių priekinis ir užpakalinis paviršiais apvirinti Fe-C-Cr-Nb-Mo-W-B lydiniais, dyla 35 % (pagal masę) lėčiau už naujus kaltus ir trumpėja iki šešių kartų lėčiau.

Noragų pjovimo briaunų apvirinimas kietaisiais sluoksniais efektyvus tik tol, kol nudyla apvirintas sluoksnis. Siekiant maksimalaus dirvos dirbimo elementų ilgaamžiškumo, turi būti dengiamas kiek galima didesnis priekinio paviršiaus plotas.

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RESEARCH OF STRENGTHENING PLOUGH PARTS BY WELDING

S u m m a r y

The principal objective of this research is to determine the increase in service life of machine elements working under intensive abrasive wear conditions achieved by alloying. The worn plough points have been analyzed. The manufacture test results of the plough points alloyed with hard layers of different composition are presented. Plough points with their alloyed rear surface are found to wear more intensively, whereas their shrinkage is slower than that of nonalloyed ones. Working parts are sensitive to the heat effect of welding, therefore they should not be strengthened by alloying their rear surface. The plough points with welded front and rear surfaces with Fe-C-Cr-Nb-Mo-W-B alloys wear (their mass) 35 % slower than the new points and they shrink also 6 times slower. In strengthened parts the most intensively wearing spots change, thus the maximum service life of the parts can be determined by additionally analyzing shape dimensions of the strengthened surfaces.

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А. Андрюшис

ИСПЫТАНИЯ НАПЛАВКОЙ УПРОЧНЕННЫХ ДЕТАЛЕЙ ПЛУГА

Р е з ю м е

В работе приведены результаты производственных испытаний долговечности упрочненных плужных долотов и лемехов, наплавленных твердыми слоями разного химического состава. Установлено, что долота с наплавленной нижней рабочей поверхностью, изнашиваются быстрее, но длина уменьшается медленнее по сравнению с ненаправленными долотами. Закаленные долоты являются чувствительными к термическому воздействию наплавки, поэтому не следует наплавлять их нижние поверхности. Износ частично наплавленной верхней поверхности по массе на 35 % меньше по сравнению с новыми долотами, а по длине – до 6 раз. Соотношение уменьшения длин (износов) нового и верхней наплавленной поверхностью (с режущем ребром) долотов, соответствует разнице износостойкости материалов в условиях проведения испытании.

Наименьшее изнашивание долотов обеспечивает наплавка верхних поверхностей твердыми слоями типа Fe-C-Cr-Nb-Mo-W-B.

Наплавка режущих кромок лемехов эффективна до износа наплавленного слоя. Испытания лемехов до предельного состояния не дало надежной разницы износа как по длине, так и по массе.

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