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UPGRADING OF MACHINES FOR SURFACE TILLAGE (FOR CULTIVATORS)

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ПІДВИЩЕННЯ ТЕХНІЧНОГО РІВНЯ МАШИН ДЛЯ ПОВЕРХНЕВОЇ ОБРОБКИ ГРУНТУ (НА ПРИКЛАДІ КУЛЬТИВАТОРІВ)

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ПОВЫШЕНИЕ ТЕХНИЧЕСКОГО УРОВНЯ МАШИН ДЛЯ ПОВЕРХНОСТНОЙ ОБРАБОТКИ ПОЧВЫ (НА ПРИМЕРЕ КУЛЬТИВАТОРОВ)

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Abstract. The article presents analysis of the state of crop production in Ukraine. It was established that in 2014, 45613 agricultural enterprises were registered in Ukraine, among them 24596 were small farms with area less than 50 hectares. All small farms and most of large enterprises (holdings) use traditional farming technologies, which assume cultivation as the prime method for surface and presowing tillage. For this purpose, cultivators are widely used, whose operational drawbacks are described in the article.

It is stated that design concept of parallelogram mechanism for cultivators based on metal friction elements has exhausted itself. In order to improve reliability of machines and stability of operating depth, it is proposed to use sliding bearings made of polymer composites. Six composites were used for the study: polyamide 6,6; filled with fiberglass and carbon fiber.

Analysis of literature showed that such scientists as Abramov L.M., Kreidlin L.M., Klimchuk Y.F., Burya O. I., Tsurpal I.A., Murgas M. and others were involved into the problem of introduction and development of structural plastics in agricultural machines. However, their researches did not concern machines for surface tillage and cultivators, in particular.

Several of the most common structural plastics were used for studying the properties: Nylon 66, PA-6-210X, PA6 / 6.6 R196-GF30, Kocetal GF705, Kocetal K300 and CCPA-6-30.

The purpose of this work is to design and implement parts made of structural plastics into movable joints of cultivators. Properties of the movable joints were studied by original and standard methods: friction and wear, abrasive wear.

In the article, results of comparison of characteristics of the most widespread polymers and composites on their basis are presented.

It was established that carbon plastic features the best tribotechnical characteristics with coefficient of friction being 0.16, while for all other materials this index was within 0.21…0.49. Carbon fiber wear was also by one order lower.

Basing on laboratory results, it is proposed to modernize design of cultivators through the use of polymer composite materials. We also recommend to use polymer composite UPA-6-30 in the parallelogram mechanism of cultivators. It is further recommended to treat the parts in oil before their installation. Such design and technology for making parts of carbon plastic do not require their further maintenance.

The technology was implemented by the company Soyuz-Composite and introduced into educational process of the Dnipro State Agrarian and Economic University.

Keywords: carbon plastic, cultivator, tribotechnical characteristic, abrasive.

1. Introduction.

Ukraine is one of the largest agrarian countries. In 2014, the area of arable land in Ukraine was 32531 thousand hectares. The largest latifundists, which occupied about 15 % of arable land, were such agroholdings as Ukrlandfarming (630000 hectares), NCH (430000 hectares), Kernel Group (700000 hectares) and others [1]. Small farms occupied 12, and about 73 % – other agro-enterprises of different sizes and forms of ownership. At the same time about half of the crop of early grain and leguminous crops for export. These crops were grown for intensive, industrial technologies using modern methods of seed preparation, chemical protection and plant care, and others.

Table 1 – Grouping of agricultural enterprises by size of sown area in Ukraine [2]

Area, hectare	Number of enterprises, units	In % to the total	Sown area, thousand hectares	In % of total area
All of them:	45613	100	19811,2	100
20,0… 50,0	24596	53,9	548,3	2,8
50,1…100,0	4606	10,1	338,2	1,7
100,1…250,0	4713	10,3	774,1	3,9
250,1…500,0	3232	7,1	1171,5	5,9
500,1…1000,0	2925	6,4	2103,6	10,6
1000,1…2000,0	2822	6,2	4045,7	20,4
2000,1…3000,0	1277	2,8	3096,9	15,6
More then 3000,0	1442	3,2	7732,9	39,1

It is concluded that the main agricultural enterprises in Ukraine are farms with an area of more than 3000 hectares. It occupy 39.1 % of the total acreage, their number at the same time is only 3.2 % of the total number of farms. Most of these enterprises are used in the cultivator processing system for presowing continuous tillage.

We have investigated that it is possible to increase the rate of work on surface tillage (cultivation) by using new materials that have high tribological properties and do not require maintenance (lubrication). Such materials include polymeric composites.

Technological progress was based exclusively on the use of natural materials – wood, stone, metals, by the beginning of the twentieth century.

The human used natural polymers for many years: cellulose, rubber, leather. Synthetic polymers were first obtained in the first half of the twentieth century, this is the beginning of the century of synthetic polymer materials.

Now a special place in the modernization of machines belongs to plastics, increasing their reliability, reducing metal consumption. The unique properties of plastics improve designs, improve their quality, reduce cost, increase labor productivity [3, 4].

Plastics used in engineering are divided into five groups: decorative, structural, antifriction, anticorrosive, electrical insulating.

To improve the technical level of machines and agricultural machinery use structural and antifriction plastics. For this purpose: polyamides, capron, polyethylene with various dispersed and fibrous fillers are often used.

Today, the use of complex plastics with different modifiers and fillers form a new group of high-tech materials – polymer composite materials. Application of polymeric composite materials in engineering and agriculture occupies an important place. This also applies to soil-cultivating machinery, which is improved for agronomic requirements [4].

Literature Review.

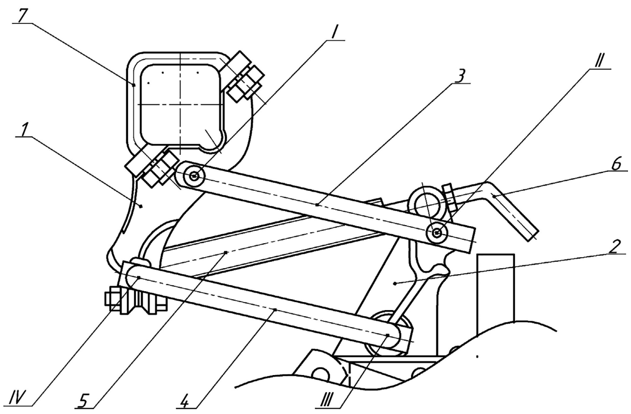
The problem of the development and introduction of new structural plastics in agricultural machinery was investigated by many scientists, such as Abramov L.M., Kreidlin L.M., Klimchuk Y.F., Burya O. I., Tsurpal I.A., Murgas M. and others. The aging processes of plastics and heat treatment methods were studied to optimize the physico-mechanical and chemical properties of articles. The results obtained in the research and introduction of polymeric composite materials in agricultural crops. engineering showed that the use of carbon plastics gives good results, because they simultaneously combine a wide range of properties, this is not present in other materials and composites. When using them in agricultural machines, the resource, reliability, and energy intensity are increased. A carbon fiber based on polyamide-6 (6,6, 12 and others) and phenolone are used. The problems of introducing polymeric composite materials into the design of modern complex seeding complexes have been solved and realized [3].

Machines for surface tillage combine the methods of processing with different tools to a depth of up to 16 cm. These are lushchilniki, skating rinks, harrows and cultivators. Cultivators are equipped with a parallelogram mechanism to ensure the most qualitative preparation of the soil, the main task of the mechanism is to copy the soil surface and ensure a stable seedbed.

Parallelogram mechanism of cultivators (Fig. 1) is a multi-hinged system for fastening the four-link mechanism, the links constitute a parallelogram. Such a system ensures high-quality copying of the field relief and a constant angle of the working element with respect to the field. During the operation of the parallelogram mechanism of cultivators КПС-4,0, КРН-5,6, КПС-8 Voskhod and others, faults were detected, such as intensive and premature wear of the axis of the links of the mechanism. This leads to a violation of the technological process of cultivation and non-compliance with agrotechnical requirements. The manufacturing plants introduced system lubrication of hinges with plastic materials. The frequency is 48…100 hours. But, for wide-spread cultivators, the maintenance of mechanisms leads to significant overstrain of the aggregates, which leads to a violation of the agrotechnical terms of cultivation.

Positions I, II, III, IV are the axes that are most worn out during the movement of the links of the parallelogram mechanism. We suggest placing them in bushings made of polymer composite materials that will have good physicomechanical and tribological properties.

Scientists Kozachenko O.V., Shkregal O.M., Svirin O.M., Babitsky L.F., Kuvshinov A.A., Tarasenko V.I., Mancinskiy Y.O. were engaged in the improvement of cultivator designs and their working



1 – the front bracket, 2 – the rear bracket, 3 – the upper link of the mechanism, 4 – the lower link of the mechanism, 5 – the spring, 6 – the adjusting screw, 7 – the bracket clamp, I, II, III, IV, – places of wear
Figure 1 – Parallelogram mechanism

organs. They investigated the stability of rectilinear motion, the oscillatory device of the cultivator paws, and improved the design of the working organs. However, these works were not aimed at the introduction of polymer composite materials in their design.

Based on the conducted studies, we can conclude that a promising direction in improving the design of the parallelogram mechanism is the introduction into the design of parts made of polymer composite materials.

In [4] describes the use of polymeric composite materials based on aliphatic polyamide CCPA-6-40 in this mechanism, but its increased hygroscopicity led to wedging of the hinges of the mechanism after seasonal storage. Also, sometimes materials that have a complex, low-productivity and energy-intensive processing technology have been proposed for use in similar mechanisms.

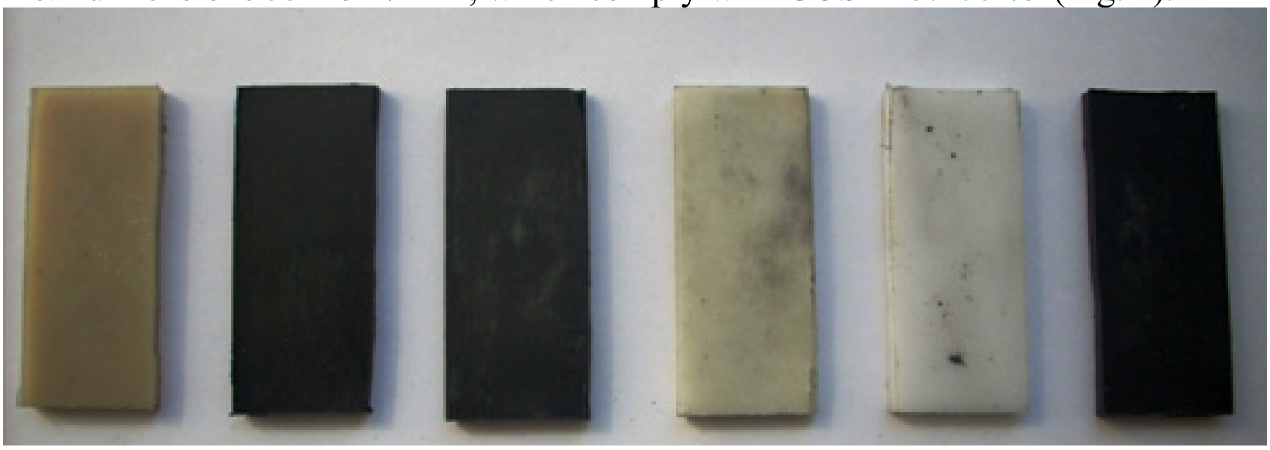
Previously, we found that polymer composite materials based on aliphatic polyamides provide a stable process of friction and wear in similar mechanisms [3].

The introduction of polymer-composite materials in the construction of mobile compounds of agricultural machines requires careful experimental studies of the characteristics and properties of polymer-composite materials, structural designation, especially tribotechnical, resource, operational, etc.

2. Materials andMethods

Methot of research of relativeabrasive stability of materials

The manufactured samples for the research of relative abrasive stability were linear dimensions 53×29×7 mm, which comply with GOST 23.208-79 (Fig. 2).



1 2 3 4 5 6

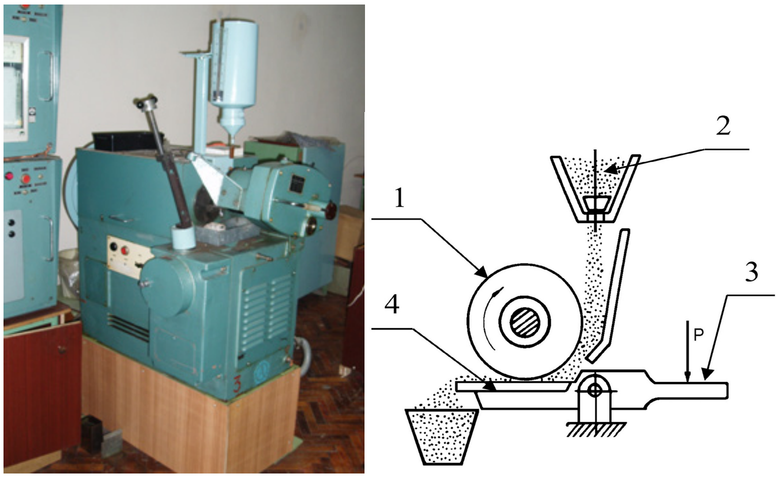
1 – Nylon 66; 2 – ПА-6-210КС; 3 – PA6/6.6 R196-GF30; 4 – Kocetal GF705; 5 – Kocetal K300; 6 – UPA-6-30

Figure 2 – General view of samples for determining relative abrasive stability

The research of samples on the relative abrasive resistance was carried out on a specially laboratory equipment installed (Fig. 3) on the basis of the friction machine SMZ-2.

The essence of the method was that under the same conditions, forced wear of the studied and reference samples was carried out. Wear was carried out using an abrasive non-rigidly fixed material (electric iron No. 16-N, GOST 3643-71), which was fed to the friction zone and pressed to the specimen with a rotating rubber roll (Fig. 3, b).

Before the test, the abrasive was dried to a relative humidity of no more than 0.16 %. The spinning of the roller was carried out by friction method on the surface of a grinding paper type 2 (GOST 6456-75) with grainy number 8P (GOST 3647-71), fixed in a sample holder on a flat steel plate. After spin, the roll was washed in gasoline. Test conditions are given in Table 2.



a b

1 – rubber roller; 2 – abrasive material; 3 – mechanism of load creation; 4 – a sample of the studied material

Figure 3 – Friction machine SMZ-2 (a) and scheme of implementation of the process of abrasive wear (b)

The following equipment was also used for research purposes: drying nozzle SNOL-465/4 I1; analytical balance of WLR-200 with an accuracy of 0.2 mg (0.0002 g); calipers ShZ-125, precision class 2, serial number E99344; other auxiliary non-standard equipment.

Table 2 – Test conditions when wearing is not hard fixed abrasive particles

Load, N	Frequency of rotation, revolutions per minute	Specification of rubber roller			
		Diameter, mm	Width, mm	Hardness according to GOST 263-75	Relative ultimate elongation,%
44	60	50 мм	15±0,1	78-85	15-20

The weight of the samples was determined by weighing before and after the test. Relative durability of the investigated material was calculated by the formula:

$$K_u = \frac{U_e \cdot \rho_\partial \cdot n_\partial}{U_\partial \cdot \rho_e \cdot n_e}, \quad (1)$$

where ρ_e, ρ_∂ – density of reference and investigated materials, kg/m^3; n_e, n_∂ – number of roller rotations during tests of reference and test samples; U_e, U_∂ – wear of reference and investigated samples, kg.

The density of samples ρ was determined by the method of hydrostatic weighing according to GOST 15139-69. The arithmetic mean value of density, obtained as a result of at least three measurements, differing no more than 1 %, was taken for the final result.

In order to compare the relative abrasive stability of the PCM, which are studied simultaneously, a reference material (Nylon 66), the absolute value of which wear was taken per unit, was selected.

Methods of determination of tribotechnical characteristics and properties of elements of movable connections.

The study of the properties of moving compounds materials was carried out on the basis of original and standard techniques.

Tribotechnical characteristics of parts of mobile joints with PCM when not rubbed greased were determined on a friction and wear machine СМЦ-2.

Indicators of the potentiometer КСП-2 were fixed on a special chart paper GOST 7826-75. The tests were performed according to the "disk-block" scheme. The radius of the sample was $R = 0.025$ m.

Before the beginning of each test, the samples were cleaned. This was done so that the friction surfaces of the samples had a parallel shape and the contact area was at least 85 %.

Friction coefficient of slip was determined by the formula:

$$f = \frac{M_{кр}}{P \cdot \Delta}, \quad (2)$$

where M_{kp} – the torque that occurs on the disk, H·m; P – load on the sample, H; Δ – step of the paper, m. For all experiments the same, $\Delta = 0{,}0025$ m.

The temperature in the friction zone was measured using the chromed-alumel electronic thermocouple «Termometer 301 Type K». The hole for measuring the temperature is carried out at a depth equal to half the diameter of the sample, and at a distance of 1 mm from the surface of the friction.

The contact area of the tribo-conection «disc disk» was 2 cm^2. Study mode: $p = 0.5$ MPa, $v = 0.785$ m/s. The process of rubbing occurred in the following modes: maximum specific pressure $p = 0{,}25$ MPa, slip velocity $v = 0{,}785$ m/s. It the curing process was completed when reaching the contact area of the pad with a conjugate sample of 85 % of the projection area.

The number of repetitions of all experiments is 3.

Thermal treatment method for protection against environmental impact.

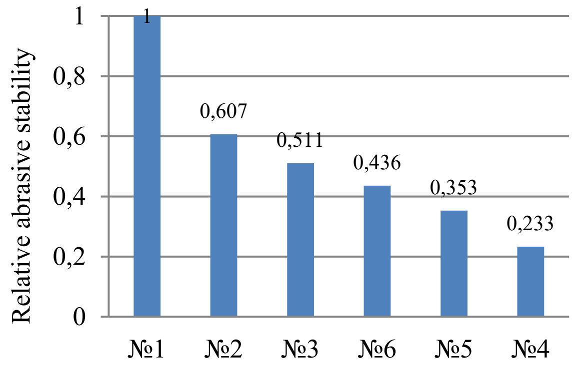
In order to solve the problem of protection of PCM from the negative influence of the external environment, it is proposed to heat the finished parts processing with PCM in the following lubricants: MS-20, PMS-400, and I-40.

Thermal treatment of composite materials:

- temperature – 393 K;
- heating and cooling mode – 1 K/min;
- exposure time – 120 min.

3. Results and Discussion

Six types of high-molecular compounds were used to study materials of parts made of polymer-composite materials: Nylon 66, PA-6-210X, PA6 / 6.6 R196-GF30, Kocetal GF705, KocetalK300 and CCPA-6-30. The research carried out on the relative abrasive stability of polymer composite materials, which showed (Fig. 4), that sample № 1 (Nylon 66) has the highest relative abrasive resistance and substantially differs positively from other materials. The visual ranking of samples according to the criterion of relative abrasive stability showed, that the Kocetal GF705 material (5 times lower than standard) has the lowest abrasive durability.



№ 1 – Nylon 66; № 2 – PA-6-210KS; №3 – PA6 / 6.6 R196-GF30; № 4 – KocetalGF705; № 5 – KocetalK300; №. 6 – CCPA-6-30

Figure 4 – Ranking of experimental samples according to the criterion of relative abrasive stability

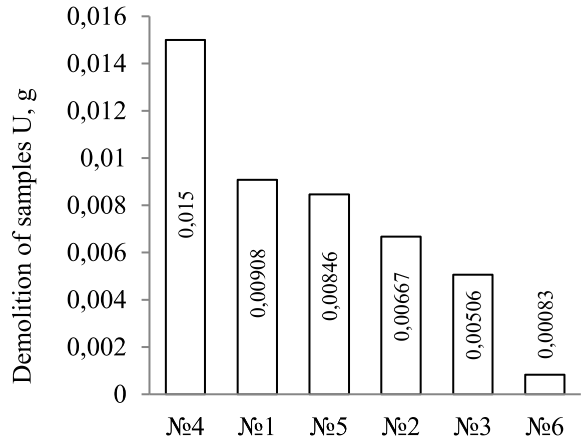
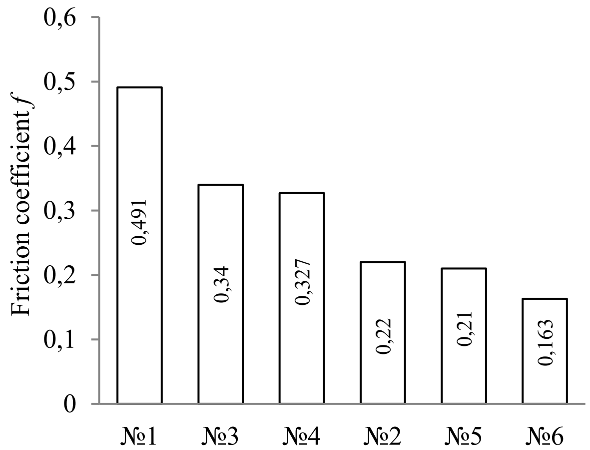
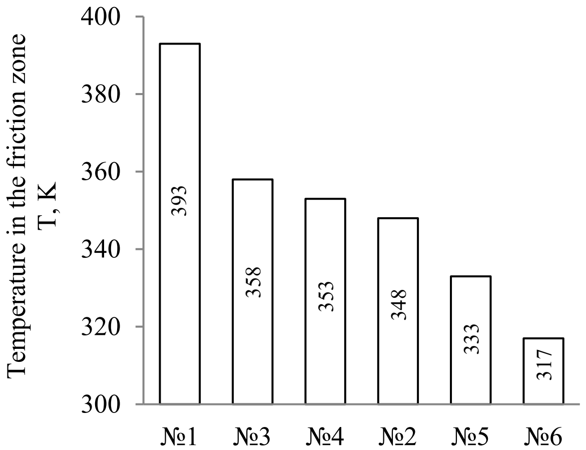


Figure 5 – The value of weight deterioration of polymer specimens with friction without lubricating on steel 45 (experimental conditions p = 0.5 MPa, v = 0.785 m/s)



№ 1 – Nylon 66; № 2 – ПА-6-210КС; № 3 – PA6/6.6 R196-GF30; № 4 – KocetalGF705; № 5 – KocetalK300; № 6 – Friction coefficient

Figure 6 – Friction coefficient in the frictional interaction of a steel conjugate sample with polymer specimens



№ 1 – Nylon 66; № 2 – ПА-6-210КС; № 3 – PA6/6.6 R196-GF30; № 4 – KocetalGF705; № 5 – KocetalK300; № 6 – UPA-6-30

Figure 7 – Temperature in the friction zone in the frictional interaction of the steel conjugate part with polymer samples

Experimental studies of tribotechnical characteristics of PCM have been performed, which showed that under identical test conditions, with a factor of pv = 0,392 MPa·m/s, the minimum wear was made from samples made from CCPA-6-30, the maximum wear – samples made of Kocetal material GF705 (Fig. 5). In addition, other polymer-composite materials have a value of wear, an order of magnitude larger than CCPA-6-30.

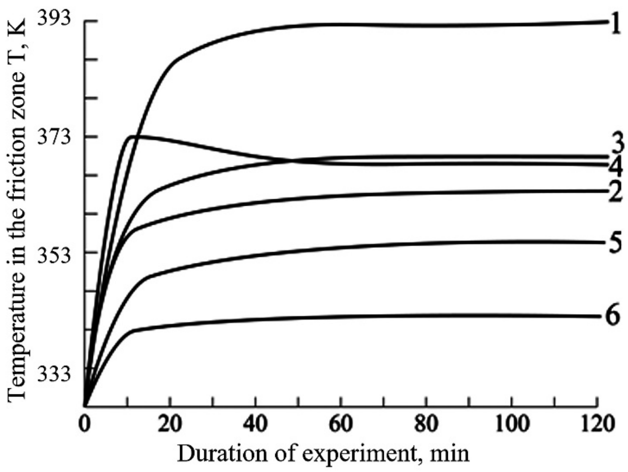
Determination of friction coefficient f showed that its value is within the limits of 0,163…0,491 (Fig. 6). The results of the temperature research in the friction zone (Fig. 7) indicate that this parameter correlates with the values of friction coefficient f.

Stabilization of temperature T in the friction zone for all samples comes in the range of 8 minutes. (for Kocetal GF705) up to 40 minutes (Nylon 66) (Fig. 8).

The general view of the experimental parts made of polymeric-composite material CCPA-6-30 is shown in Fig. 9

We have developed methods for heat treatment in oils, which make it impossible to hygroscopic PKM based on aliphatic polyamides in volumes that led to a change in geometric dimensions or changes in properties.

The results of the research have shown that the Nylon 66 PCM, which provides relative abrasive stability, is 39 % higher than the PA-6-210X composite and 77 % higher than Kocetal GF705.



№ 1 – Nylon 66; № 2 – ПА-6-210КС; № 3 – PA6/6.6 R196-GF30; № 4 – KocetalGF705; № 5 – KocetalK300; № 6 – UPA-6-30

Figure 8 – Dependence of temperature on the friction surface in the frictional interaction of the steel conjugate sample with the polymer samples from the time of the experiment

a

b

Figure 9 – General view of experimental details: a – details of the upper lever; b – details of the lower lever

Table 2 – Influence of heat treatment in oil on the strength of polymeric composite materials of grade CCPA-6-30

Parameter	Control	After processing	Deviation, %
Strength of compression strength σ, MPa	134,7	133,1	1,18
Modulus of elasticity E, MPa	1883,1	1743,9	7,39

It is not recommended to use as abrasive resistant materials Kocetal GF705 and Kocetal K300.

On the basis of the obtained data it can be assumed that the materials of the specimens for №№2, 5, 6 are antifriction because they have a coefficient of friction $f < 0.3$, and the materials of the specimens for №№ 1, 3, 4 are frictional materials with moderate high coefficient of friction, therefore their use in movable connection of cultivators is inappropriate.

The research of the dependence of friction coefficient f on the duration of the experiment showed that the stabilization f for all samples comes after 3…22 min. from the beginning of the test. For samples № 2 – 6, during 120 minutes, *f* did not increase, or its deviations were within the measurement error. Only when tested with a Nylon 66 PCM sample this indicator slightly increased steadily. The growth rate of this parameter was 0.01 h^{-1}.

In order to ensure the stable operation of mobile machines and mechanisms operating under conditions of friction without lubrication and a small amount of abrasive, it is recommended to use a polymer composite – UPA-6-30, which at a specific pressure p = 0.5 MPa and slip velocity v = 0,785 m/s provides a minimum friction coefficient (f = 0,16), temperature in the friction zone (T = 313 K); their own wear, which is an order of magnitude smaller than the other samples being studied. This composite has stable performance over long periods of operation.

In general, the proposed method of heat treatment reduced the hygroscopicity of this polymer composite material, and the amount of moisture accumulated during the storage of equipment decreased from 0.70 % to 0.35.

This technology is realized in Development Enterprise “Soyuz-Composite” and recognized as cost-effective.

4. Conclusion

The use of polymer composite materiales in hinged joints of parallelogram mechanisms of soil tillage machines will improve the quality of the implementation of agrotechnical requirements, eliminate the cost of idle time during the maintenance of mechanisms, reduce the cost of operation and maintenance of modernized cultivators.

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Анотація. У статті представлений аналіз стану рослинництва в Україні. Встановлено, що за станом на 2014 рік, в Україні зареєстровано 45613 аграрних підприємств, 24596 серед яких – малі фермерські господарства, площею до 50 га. Всі малі фермерські господарства і переважна більшість з великих підприємств (холдингів) використовують традиційні технології землеробства. У традиційній системі землеробства передбачається, що культивація є переважним способом поверхневої і передпосівної обробки ґрунту. Для цього широко використовуються культиватори. Наведено опис недоліків в роботі культиваторів.

Встановлено, що концепція конструкції паралелограмного механізму культиваторів, на основі металевих елементів тертя себе вичерпала. Надійність існуючих конструкцій культиваторів низька, рухливі з'єднання потребують постійного технічного обслуговування з малою періодичністю. Заклинювання рухомих з'єднань культиваторів також призводило до порушення глибини обробки. Запропоновано для підвищення надійності та стабільності глибини обробки використовувати підшипники ковзання, виготовлені з полімерних композитів.

Літературний аналіз показав, що проблемою впровадження і розробкою конструкційних пластиків в сільськогосподарських машинах займалися такі вчені, як Абрамов Л.М., Крейдлін Л.М., Климчук Ю.Ф., Буря О.І., Цурпал І.А., Murgas M. та інші. Однак, їх дослідження не торкалися машин для поверхневої обробки ґрунту, зокрема, культиваторів.

Для досліджень властивостей були використані декілька найбільш поширених конструкційних пластиків: Nylon 66, PA-6-210X, PA6 / 6.6 R196-GF30, KocetalGF705, KocetalK300 і CCPA-6-30.

Метою даної роботи є розробка конструкції і впровадження деталей виготовлених з конструкційних пластиків в рухливі з'єднання культиваторів. Вивчення властивостей деталей рухомих з'єднань проводилось на основі оригінальних та стандартних методів: тертя і зношування, абразивний знос.

У статті наведено результати досліджень порівняльних характеристик найбільш поширених полімерів і композитів на їх основі.

Встановлено, що найкращими триботехническими характеристиками володіє вуглепластик, який має коефіцієнт тертя – 0,16, в той час як у всіх інших матеріалів цей показник був в межах 0,21...0,49. Також було зафіксовано на порядок нижчий знос вуглепластика.

На основі результатів лабораторних досліджень було запропоновано модернізувати будівництво культиваторів за допомогою полімерних композиційних матеріалів. Ми рекомендуємо введення полімерного композиту УПА-6-30 в конструкцію паралелограмного механізму культиваторів. Для зниження негативного впливу вологи на вказаний полімерний композит, рекомендовано деталі перед установкою обробляти в маслі. Така конструкція і технологія виробництва деталей з вуглепластиків не вимагають подальшого обслуговування.

Технологія впроваджена в підприємстві «Союз-Композит» і впроваджена в навчальний процес Дніпровського державного аграрно-економічного університету. Економічний ефект від використання розробки позитивний.

Ключові слова: вуглецевий пластик, культиватор, триботехнічних характеристик, абразив.

Аннотация. В статье представлен анализ состояния растениеводства в Украине. Установлено, что по состоянию на 2014 год, в Украине зарегистрировано 45613 аграрных предприятий, 24596 среди которых – малые фермерские хозяйства, площадью до 50 га. Все малые фермерские хозяйства и подавляющее большинство из крупных предприятий (холдингов) используют традиционные технологии земледелия. В традиционной системе земледелия предусматривается, что культивация является преимущественным способом поверхностной и предпосевной обработки почвы. Для этого широко используются культиваторы. Приведено описание недостатков в работе культиваторов.

Установлено, что концепция конструкции параллелограммного механизма культиваторов, на основе металлических элементов трения себя исчерпала. Надёжность существующих конструкций культиваторов низкая, подвижные соединения нуждаются в постоянном техническом обслуживании с малой периодичностью. Заклинивание подвижных соединений культиваторов также приводило к нарушению глубины обработки. Предложено для повышения надёжности и стабильности глубины обработки использовать подшипники скольжения, изготовленные из полимерных композитов.

Литературный анализ показал, что проблемой внедрения и разработкой конструкционных пластиков в сельскохозяйственных машинах занимались такие учёные, как Абрамов Л.М., Крейдлин Л.М., Климчук Ю.Ф., Буря О.И., Цурпал И.А., Murgas M. и другие. Однако, их исследования не касались машин для поверхностной обработки почвы, в частности, культиваторов.

Для исследований свойств были использованы несколько наиболее распространенных конструкционных пластиков: Nylon 66, PA-6-210X, PA6 / 6.6 R196-GF30, KocetalGF705, KocetalK300 и СCPA-6-30.

Целью данной работы является разработка конструкции и внедрение деталей изготовленных из конструкционных пластиков в подвижные соединения культиваторов. Изучение свойств деталей подвижных соединений проводилось на основе оригинальных и стандартных методов: трение и изнашивание, абразивный износ.

В статье приведены результаты исследований сравнительных характеристик наиболее распространённых полимеров и композитов на их основе.

Установлено, что лучшими триботехническими характеристиками обладает углепластик, который имеет коэффициент трения – 0,16, в то время как у всех остальных материалов этот показатель был в пределах 0,21…0,49. Также был зафиксирован на порядок ниже износ углепластика.

На основе результатов лабораторных исследований было предложено модернизировать строительство культиваторов с помощью полимерных композиционных материалов. Мы рекомендуем введение полимерного композита УПА-6-30 в конструкцию параллелограммного механизма культиваторов. Для снижения негативного влияния влаги на указанный полимерный композит, рекомендовано детали перед установкой обрабатывать в масле. Такая конструкция и технология производства деталей из углепластиков не требуют дальнейшего обслуживания.

Технология внедрена в предприятии «Союз-Композит» и внедрена в учебный процесс Днепровского государственного аграрно-экономического университета. Экономический эффект от использования разработки положительный.

Ключевые слова: углеродистый пластик, культиватор, триботехническая характеристика, абразив.

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