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UNUSUAL POSSIBILITY OF WEAR RESISTANCE INCREASE RESEARCH IN THE SPHERE OF SOIL CULTIVATION

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Original scientific paper
Machines, equipment and their partial segments used in agriculture, namely in the sphere of soil cultivating, are exposed to an intensive abrasive wear. Important producers of agricultural machines use sintered carbides, namely the tungsten carbide in the soil cultivating tools. The alternative to this solution is introducing the ceramic materials which have proved their positive wear resistance. This paper deals with the application possibility of the ceramic materials and adhesives in the tools used for cultivating the soil. Laboratory tests showed that a suitable choice of adhesive increased the system rigidity which means the energy absorption was increased during the impact on the ceramic surface. The ceramic Al_2O_3 was tested. The aim of the research is the evaluation of shear impact strength of adhesive bonds and the possibilities of using the ceramic materials as the wear resistant materials in the sphere of soil cultivation. Application of this solution demands coping with the adhesive bonding technology in obtaining firm and strong bonds which means the ceramics/steel interaction.

Keywords: *adhesive bond, ceramics, shear impact strength, wear resistance*

Posebna mogućnost istraživanja povećanja otpornosti na trošenje u području obrade tla

Izvorni znanstveni članak
Strojevi, oprema i njihovi dijelovi koji se koriste u poljoprivredi, naime u području obrade tla, izloženi su intenzivnom abrazijskom trošenju. Važni proizvođači poljoprivednih strojeva upotrebljavaju sinterirane karbide, naime tungstenov karbid, u alatima za obradu tla. Alternativa ovom rješenju je uvođenje keramičkih materijala koji su se dokazali pozitivnim otporom na trošenje. Ovaj se rad bavi mogućnošću primjene keramičkih materijala i ljepila u alatima korištenim za obradu tla. Laboratorijska ispitivanja pokazala su da se odgovarajućim izborom ljepila povećala krutost sustava što znači da je porasla apsorpcija energije tijekom udara na keramičku površinu. Ispitivan je keramički materijal Al_2O_3. Cilj istraživanja je procjena jačine smičnog udara adhezivnih spojeva i mogućnosti uporabe keramičkih materijala kao materijala otpornih na trošenje u području obrade tla. Primjena tog rješenja zahtijeva bavljenje tehnologijom adhezivnog spajanja pri dobivanju postojanih i čvrstih spojeva, a to znači međudjelovanje keramika/čelik.

Ključne riječi: *adhezivni spoj, keramika, otpornost na trošenje, smična čvrstoća udara*

1 Introduction

Complexity and sustainability of systems in agriculture are key factors, namely in an integration with keeping an ability to secure aliment and connected food stuff production. One of the means reaching the sustainability in the sphere of food production can be the conventional soil cultivating. Machines, equipment and their partial segments used in agriculture are exposed to an intensive abrasive wear, namely in the sphere of soil cultivation. Regarding the wear conditions and the process intensity is an integral part of a lifetime and reliability not only of tools, but also the whole systems. Currently many experts deal with the problems of increasing the lifetime of segments cultivating the soil [2, 3, 6, 7, 9, 10]. Both the producers of machines for the soil cultivating and many research institutes all over the world are included in intensive research. The research aim of various working groups can be defined as the following: finding suitable materials and methods for the production of optimum tools whose mechanical properties would extend the tools lifetime and they would decrease the energy consumption of the soil cultivating owing to the lower resistance. The possible solution is a creation of bimetallic tools on one hand and various additional materials on the other hand. Bonding methods are the defined problem of various materials. Currently the brazing and soldering are used. However, this method is expensive and it cannot be applied in all cases. An adhesive bonding is the general bonding technology which enables to bond heterogeneous materials in effective way. This technology is not innovated in the field of bonding tools for the moment. The tool wear can be decreased by using high wear resistant material. The wear resistance increasing of the soil cultivating tools leads to the increase of the tool lifetime and to the decrease of the energy consumption demands. Above mentioned presumption defines explicitly the priority of research of the wear resistance increase possibilities. Sintered carbides are the most widespread cutting material these days. Important producers of exchangeable parts of the soil cultivating machines increase the wear resistance of their tools owing to e. g. the tungsten carbide. However, when the soil cultivating, significant tool wear occurs which is connected with the wastage of this tool. Microscopic particles get unbarred into the soil and the tungsten carbide can contaminate the soil when it is applied. A similar problematic tendency can be observed at hardfaced overlays containing the chromium, vanadium and tungsten. This fact leads to the necessity to take into regard also the soil chemistry when solving the wear resistance. The effectivity of high chrome overlays is investigated by many authors, e.g. Chotěborský et al. [4]. When cultivating the soil it is necessary to take into regard also the impact dynamic point of view that means the material toughness which affects the integrity of not only the surface layers in the negative way. Among unusual ways of increasing the wear resistance is the application of the technical ceramics and so creation of new functional surfaces. The problematic aspect is not the sufficient wear resistance of the tool, but its fragility. The essential point of view in soil cultivating is namely the dynamic behaviour of the whole system in contact with the soil. Suchánek et al. state that Al_2O_3 and ZrO_2 are suitable as the ceramic materials exposed to the conditions of the intensive abrasion [1, 8]. Experiments with the dry rubber wheel carried out according to ASTM G65 proved that the tested oxide ceramics were of the same wear resistance as WC – NiCr and Cr_3C_2. The high wear resistance is explained by very uniform microstructure with a small volume of glassy phase. Also Medvedovski found out similar conclusions. He states the laboratory test results of various ceramic materials [5]. Stated values of the wear are tested in accordance with ASTM B611 and ASTM G65. In his book Suchánek states the fundamental knowledge that the higher toughness and higher hardness of the ceramic material is, the better is its wear resistance under conditions of the abrasive wear [1]. This statement is not valid for metals at which the increased wear resistance and hardness are often reached of detriment to lower fracture toughness. The paper presents the results of the research focused on using the adhesive bonding technology as the possible way for bonding or securing various accessory materials distinguished for increased wear resistance. The tool wear can be decreased not only by the material distinguished for increased wear resistance but also by the accessory equipment which solves the given problem in the effective way. Then it is possible to speak about the constructional solution which requires finding suitable bonding technology. The disadvantage of the adhesive bonding technology is namely low impact strength. This fact is essential in the application in the sphere of exchangeable wear parts used in cultivating the soil. The integral part of the research work is the evaluation of not only the own impact strength, but also the temperature affecting the adhesive. The research aim is to evaluate the possibility of ceramic materials application as the potential wear resistant material in the sphere of the soil cultivating. The application of this solution requires knowing the adhesive bonding technology in the sphere of firm and sufficiently strong bond that means the interaction ceramics/steel.

2 Methodology

An untraditional material applied to the soil cultivating tools is the technical ceramics distinguished for high wear resistance. Ceramic plates based on Al_2O_3 (92 and 96 %) of sizes 25 × 25 × 6 mm were tested. Ceramic plates were adhesive bonded with the epoxy adhesive to the basic material – steel (S235J0). The adhesive bonded surface of the ceramic plate was not mechanically nor chemically treated. The adhesive bonded steel surface was eroded by Al_2O_3 of the fraction size F80 and consequently chemically cleaned. One group of samples was not adhesive bonded to the basic material but it was fixed by means of locks. Tests were carried out according to modified Charpy test valid for metal materials with 25 J impact hammer [11]. The modification consisted in the fact that there was not kerf on the impact area of the ceramic plate. The impact hammer fell on the level area of the ceramic plate which was adhesive bonded to the steel basic material. The adhesive layer thickness 0,65 ± 0,05 mm was the same for all tests. The testing process was carried out at the temperatures 22 ± 2 °C and 100 ± 2 °C. The tests were carried out in 20 cycles that means in repeated impact of the impact hammer working part until the first discontinuities in surface layers occurred (speed 14 km per hour). Then the shear impact strength of adhesive bonds (steel/steel, bottom sizes of the sample 45 × 25 × 20 mm, upper size 25 × 25 × 10 mm) was tested which simulated in effective way the conditions of presumed loading in practical application i.e. in the soil cultivating. The laboratory test course is described in the standard CSN EN ISO 965 which states mainly the shape and sizes of the tested samples [12]. However, the suitable constructional setting of the tested equipment is not defined. Adhesive bonds were left under the laboratory conditions (temperature 22 ± 2 °C) for hardening for 48 hours. Testing was carried out on developed equipment at temperatures 20 °C, 60 °C and 100 °C (temperatures 60 °C and 100 °C were reached in the laboratory chamber). The following adhesives were tested: adhesives based on two-component epoxy adhesives, metyl-methacrylates, based on aminoetylaminopropyltrimetoxysilan, polyester, cyanoacrylates and the polymeric particle composite system (matrix – epoxy adhesive, filler – rubber). The following list presents the identification of tested adhesives and their identification which is used in the text for better arrangement:

- Two-component epoxy adhesive Loctite Nordbak 7256 (LN7256),
- Two-component epoxy adhesive Lepox 1200 (L1200),
- Two-component epoxy adhesive UHU Plus endfest epoxy 300 (UHU300),
- Two-component epoxy adhesive 3-TON Epoxy adhesive 30 min (3TON),
- Metyl-methacrylat Novatit (N-MET),
- Metyl-methacrylat UHU plus multifest (UHUM),
- Polyester MTB (MTB),
- Adhesive based on aminoetylaminopropyltrimetoxysilan Novatmel (N-tmel),
- Cyanoacrylate adhesive Novax (N-K),
- Polymeric particle composite system – matrix: two-component epoxy adhesive Lepox 1200, filler in form of rubber (KLP).

It is essential to observe the temperature influence during the laboratory tests focused on the soil cultivating. The reason is the friction during the soil cultivating which increases the temperature of the tool. Many adhesives resist very little to the dynamic loading, namely impacts loading. The experimental research helps to find limits and possibilities of the adhesive bonding technology and to confirm or refute presumed hypotheses necessary before application in series. In the technical practice the impact strength is set by the Charpy method on the impact hammer [12]. For setting shear impact strength it is suitable to use the impact hammer, but it is necessary to use a different tester. However, this tester is not in the supply of the tested equipment and it has to be designed. The suggestion and design of the equipment for the evaluation of the shear impact strength of adhesive bonds was the subject of the utility pattern no. CZ 23585 U1 [13]. The subject of the utility pattern is the tester for the evaluation of the shear impact strength of adhesive bonds.

The equipment is composed of two parts, the impact hammer and the equipment part for fixing the tested sample. The constructional design of the impact hammer enables the testing variability owing to the exchangeable crashing plate provided that the conditions about the minimum width against the impact area of the tested sample given in the standard are fulfilled. The technical solution is visible in Fig. 1 and Fig. 2.

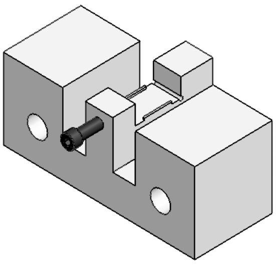

Figure 1 Apparatus for testing shear impact strength of adhesive bonds fixed in Charpy hammer

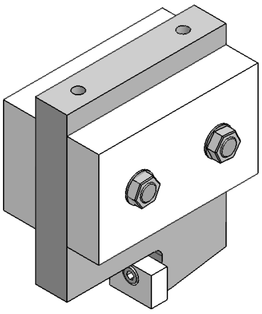

Figure 2 Impact hammer for testing shear impact strength of adhesive bonds fixed in Charpy hammer

3 Results

Testing of ceramic plates was based on Al_2O_3 (92 % and 96 %) of thickness 6 mm, impact energy 25 J, temperatures 22 ± 2 °C and 100 ± 2 °C. Tested ceramic plates without the layer of the adhesive were completely broken during the first impact (Fig. 3).

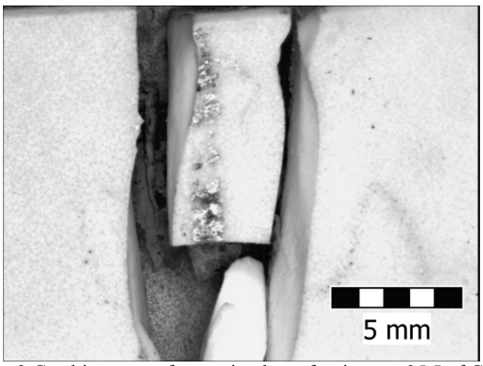

Figure 3 Crashing area of ceramic plate after impact 25 J of Charpy hammer (was not adhesive bonded)

The tested ceramic plates were fixed by means of locks to the steel basic material. Ceramic plates based on Al_2O_3 showed the ability to resist to this dynamic loading 25 J at the impact speed 14 km per hour but only in case of using the adhesive bonding technology. The number of repeating cycles was 20. Only minor failure occurred visible in Fig. 4. After reaching 20 cycles of the Charpy hammer impact it came to the delamination in the adhesive layer and consequently to gradual destruction of the ceramic plate (Fig. 5).

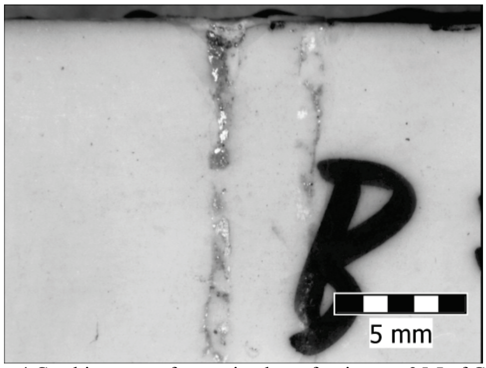

Figure 4 Crashing area of ceramic plate after impact 25 J of Charpy hammer (adhesive bonded, place of crash is marked)

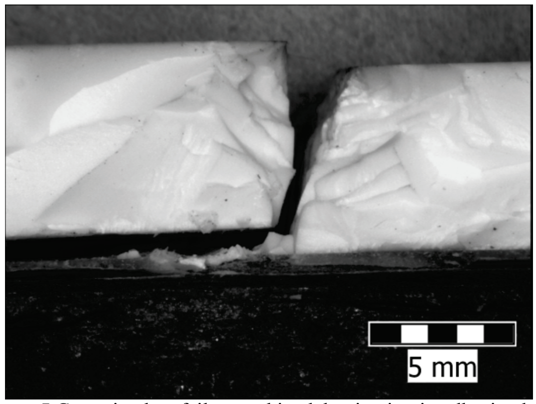

Figure 5 Ceramic plate failure and its delamination in adhesive layer

From the experiment results it could be claimed that the ceramics is a suitable wear resistant material. It defined a problem in the boundary line of the adhesive layer which had to be solved. A few types and sorts of adhesives (epoxy adhesive, acrylate, methyl-methacrylate, cyanoacrylates) were tested.

3.1 Adhesives behaved differently during testing

For application at the soil cultivating the group of adhesives distinguished for the increasing or constant shear impact strength of adhesive bonds with increasing temperature is important. When evaluating the tested set of various adhesives a great difference in the reached values was found in the interval from 3440 to 18 360 J/m^2. When testing the boundary ceramics/steel the mean value was at the adhesive N-MET and at the laboratory temperature 6360 ± 578 J/m^2. When comparing the same adhesive in the boundary steel/steel the value was at the laboratory temperature 6960 ± 1267 J/m^2. Results of the measurements showed the trend of decrease of the shear impact strength when changing the adherents, however the statistical indicators are not arguable. Fig. 6 shows the results of shear impact strength at the temperatures 22 °C, 60 °C and 100 °C. Adhesives LN7256, L1200 and KLP showed increasing trend with the increasing temperature of the application.

The failure area of the above mentioned adhesives visible in Figs. 7, 8 and 9 was of the cohesive type.

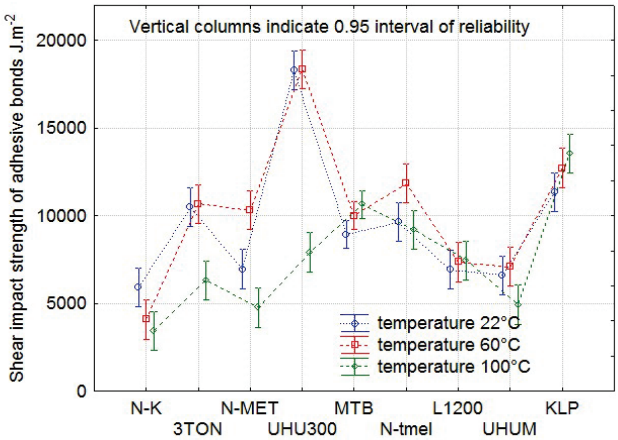

Figure 6 Shear impact strength of adhesive bonds

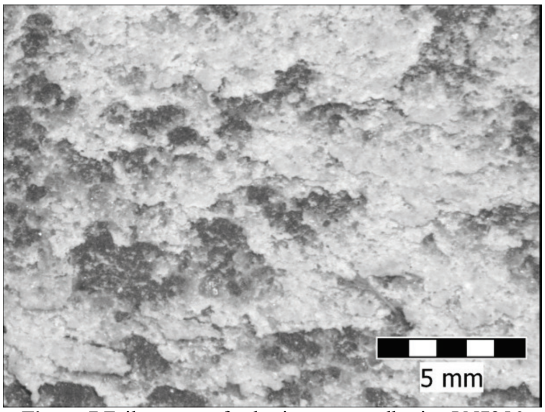

Figure 7 Failure area of cohesive type – adhesive LN7256

The research showed potential significant application of the rubber filler in the two-component epoxy adhesive. Compared with standard offered adhesive the composite system showed the increase of the shear impact strength of up to 80 %. When testing the composite system based on the two-component epoxy adhesive and the matted rubber it is essential to reach the highest possible rubber representation.

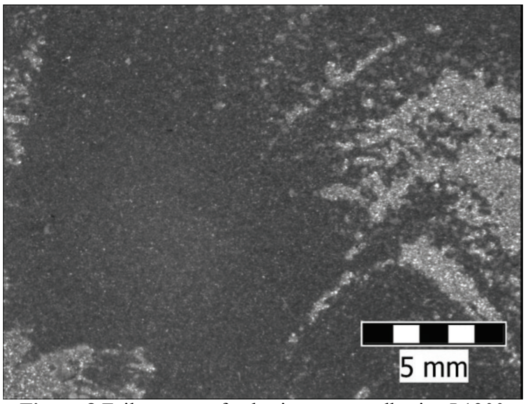

Figure 8 Failure area of cohesive type – adhesive L1200

The results showed that the final impact strength can decrease by about 30 % compared with saturated solution of prepared composite mixture. The results of composite systems based on the polymeric particle composite on the basis of grinding the retreaded tyres show wide spectrum of solutions. Secondary benefit for practical application is in up to 20 % savings of the adhesive consumption.

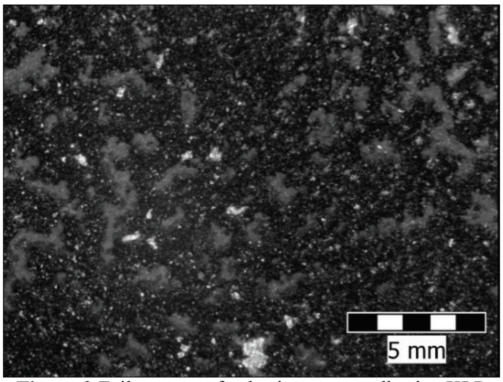

Figure 9 Failure area of cohesive type – adhesive KLP

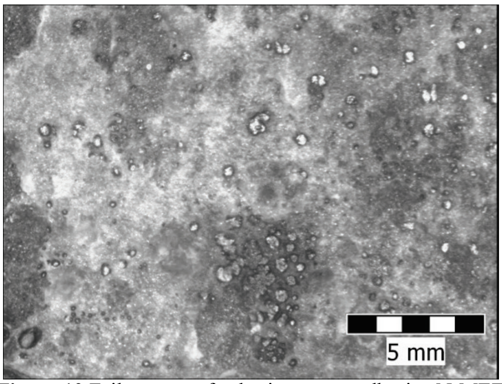

Figure 10 Failure area of cohesive type – adhesive N-MET

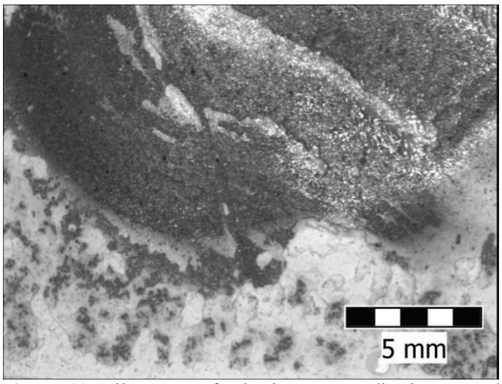

Figure 11 Failure area of cohesive type – adhesive N-tmel

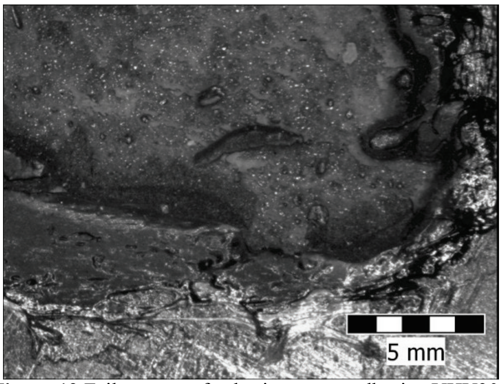

Figure 12 Failure area of cohesive type – adhesive UHU300

The second group consists of adhesives N-MET, N-tmel, UHU300 and UHUM showing the increase of the impact strength of adhesive bonds owing to the temperature until the temperature 60 °C. The failure areas of these adhesives were also of cohesive type (Figs. 10 ÷ 13).

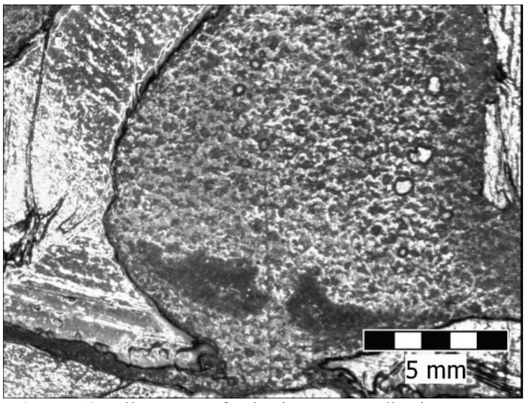

Figure 13 Failure area of cohesive type – adhesive UHUM

The third group consists of adhesives 3TON, MTB and N-K which showed the decrease of the impact strength of adhesive bonds owing to increasing temperature. These adhesives were also of cohesive failure (Figs. 14 ÷ 16).

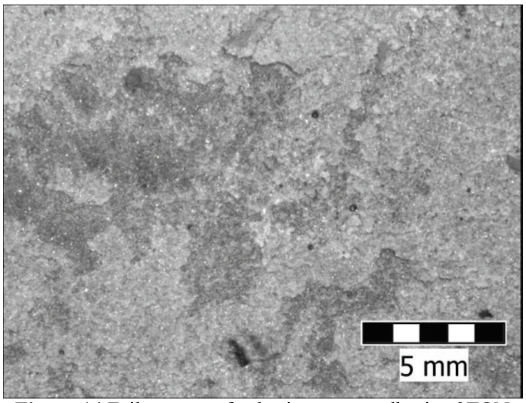

Figure 14 Failure area of cohesive type – adhesive 3TON

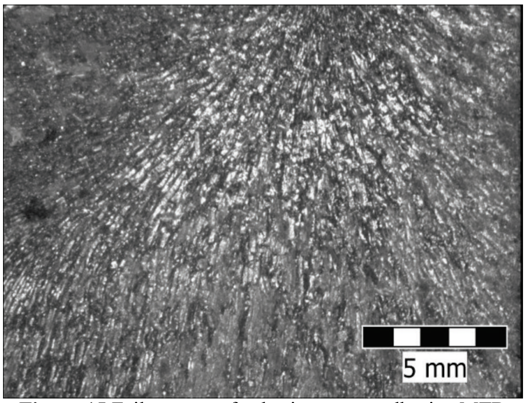

Figure 15 Failure area of cohesive type – adhesive MTB

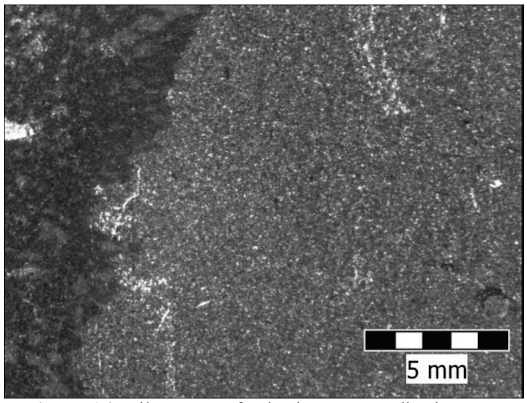

Figure 16 Failure area of cohesive type – adhesive N-K

T - test results of dependence show that the impact strength of the adhesive LN7256 (p=0,19), N-tmel (p=0,2), KLP (p=0,21) is the same as the adhesive 3TON at the laboratory temperature. The same is valid for the adhesive L1200 (p=0,94), UHUM (p=0,46) and N-MET. At the temperature 60 °C, the adhesive MTB has the same impact strength as the adhesive L1200 (p=0,6) and UHUM (p=0,4), the adhesive KLP has the same strength as the adhesive LN7256 (p=0,73) and N-tmel (p=0,12). At the temperature 100 °C, the impact strength of adhesives 3TON and MTB (p=1) are the same, the adhesive N-MET as the adhesive UHUM (p=0,69), the adhesive UHU300 as the adhesives N-tmel (p=0,12) and L1200 (p=0,24).

The analysis shows the significant dependence among the adhesive type, temperature and resulted shear impact strength (Tab. 1). The combination of the influences of the temperature and type of adhesive shows that it does not exist a general trend only about the influence of the temperature and the properties at various temperatures depending on the type of adhesive. So it is not possible to prove the decrease of the impact strength value with increasing temperature or the contrary. On the contrary, the impact strength increases till the given temperature at some adhesives and consequently the impact strength decreases with higher temperature. From the practical application point of view it is possible to recommend the developed adhesive on the basis of the polymeric particle composite with the rubber admixture. Increasing of its impact strength can be presupposed when applying the filler in the form of the rubber. It can be the topic of the next testing. Owing to its viscous nature the handling, laying on and stability in the bond during the hardening process would be significantly improved.

Table 1 ANOVA test

One dimensional tests of significance, effects of force and impact strength of adhesive bonds J/m^2					
	SS (the sum of squared deviations)	degrees of freedom	MS (mean square)	F	p
Intercept	2,368363E+10	1	2,368363E+10	7422,874	<0,001
adhesive	2,507088E+09	8	3,133860E+08	98,221	<0,002
Temperature	3,633369E+08	2	1,816684E+08	56,938	<0,003
Adhesive*temperature	8,688459E+08	16	5,430287E+07	17,019	<0,004
Error	8,710415E+08	273	3,190628E+06		

4 Conclusion

The effective solution applied in agriculture are the iron, non-iron and non-metal materials distinguished for high wear resistance which do not contaminate the soil during the wear process occurring during the soil cultivating. The disadvantage of these materials is low ability to resist to the impact of various firm particles contained in the soil. The second disadvantage is the necessity to create a firm and reliable bond. In the paper results are presented of the research focused on untraditional possibilities of increasing the wear resistance of the soil cultivating tools by means of the application of ceramic plates on exposed place of the tool. The adhesive bonding technology solves the problem by creating a sufficiently firm, elastic and temperature resistant bond. The experiments showed that the elasticity of constructional adhesives could be increased by adding the filler in the form of the rubber. The laboratory experiments confirmed that the ceramic material based on Al_2O_3 is fragile. However, the laboratory experiments proved the ability of the adhesive layer to be a damping member in the system metal/ceramics. Reaching the marginal state of the adhesive layer delamination the ceramic plate was broken consequently. The advantage of this solution is the ecological aspect of minimizing the soil contamination by the elements Cr, V and W coming from the hardfaced overlays or cemented carbides. Costs for creating bond are lower against brazing. Costs per one bond of sizes 50 × 15 mm are in the interval 0,3 ÷ 0,5 Euro (at the adhesive layer thickness 0,06 mm).

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