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Assessment of bonding quality for several commercially available adhesives

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Abstract. An adhesive bonding technology is a prospective bonding technology of diverse materials. For successful practical application, knowledge gained by studying factors that significantly influence mechanical properties of the adhesive bonds are essential. The adhesive bond rise is influenced by an increase of chemical – physical links. The adhesive bonding strengthens its position in a number of agricultural machines and tools.
The aim of the experiment is to create the adhesive bond which provides the maximum strength and quality for single combination of the adhesive and adherents, usually at minimum costs. This aim can be reached by describing the process of the hardening and ensuring the optimum adhesive layer. Describing the adhesive bonding process and its factors is essential for companies producing agricultural machinery.
From the results of the experiment there is visible a significant fall of the tensile shear strength of the adhesive bond with increasing time needed for the adhesive bond creation. The experiment results also certified the negative influence of the unequal adhesive layer on the strength fall but also a huge dispersion variance of results.

Key words: adhesive bond creation, adhesive layer thickness**,** bonding technology, time.

INTRODUCTION

An adhesive bonding strengthens its position in various agricultural machinery and tools. In agriculture, it can be mentioned, e.g. the cooperation of the firms Henkel and New Holland. Machinery, equipment and their particular segments working in agriculture are exposed to intensive abrasive wear, namely in the sphere of soil processing. Important producers of the agricultural machine use sintered carbides, namely tungsten carbide in soil processing tools (Chotěborský et al., 2009).

The adhesive bonding technology is a prospective bonding technology of diverse materials (Abel Wahab et al., 2002; Messler, 2004). For successful practical application, knowledge gained by studying factors which significantly influence mechanical properties of the adhesive bonds are essential (Prolongo et al., 2006; Herák et al., 2009). The adhesive bond rise is influenced by an increase of chemical – physical links (Müller et al., 2007).

Contemporary conclusions from the practice are distinguished by primary distrust in this technology, but after more detailed analysis of the problem the adhesive bonding technology seems to be prospective. The reason is namely the fact that the adhesive bond represents a complicated complex whose creation and following usage are influenced and also limited by many particular factors (Müller et al., 2007). The experimental research of the particular factors and their simulation are important milestones in the possibility to specify optimum values of the adhesive bond ensuring the construction reliability and decreasing the economic costs of production at the same time (Davis & Bond, 1999; Müller & Herák et al., 2010).

Today many two-component epoxy adhesives exist, whose time of reaching the handling strength is several minutes. This time can be considered as the time of maximum workability. In the adhesive the links start to form already at the mixing of two components – the resin and the hardening agent. Strong links begin to emerge among polymer molecules. A certain step of reached strength is the very handling strength. After reaching this it is possible to handle the bond. The fixation of bonded parts is important for the creation of a first-class adhesive bond. From the above mentioned information it results that almost instantly after the hardening reaction starts the links begin to form. The hardening reaction starts by the mixing of the resin and hardening agent in the specific ratio. Therefore it should not be delayed in the suitable fixation. With the contingent change of the bonded parts position failure of arising polymer chains occurs and in this way the adhesive bond strength decreases. The use of adhesives which quickly reach the handling strength is profitable in the bonding of small and less complicated parts. On the contrary their application is inconvenient with the bonding of complicated and large parts, which need, e.g. a subsequent adaptation of the bonded parts position. All the time it is necessary to prepare a new mixture, that is the cause of losses above all owing to the bad estimation of the required adhesive volume. But modern dosing devices are able to carry out the dosing and mixing of both components directly before the application.

The advantage of two-component epoxy adhesives of short workability time (2 to 5 minutes) is the fact that the complicated fixation of bonded parts position is not necessary. These adhesives are used owing to their high measure of hardening and at the same time for keeping epoxy adhesive's positive properties especially with repairs of small and uncomplicated products.

Further presented tests of the adhesive mixture workability were carried out using different times of the components mixing to the bonding. Four two-component epoxy adhesives of short workability were evaluated.

For securing the even / optimum adhesive layer thickness the following methods are used (Messler, 2004):

- Using mechanical shims, distance particles, wires, stops (they are removed or they stay).
- The application of a given filler ratio of a specific fraction size (e.g. corundum grains), which defines evenly the adhesive layer thickness.
- Using 'film adhesive' which is available in various 'starting' adhesive layer thicknesses.

- The method 'test – mistake' for determining the right combination between the pressure and the adhesive viscosity which brings the required bond thickness (common cause of problems in the practice).

The aim of the experiments is to create the adhesive bond which provides the maximum strength and the quality for single combination of the adhesive and adherents, usually at minimum costs. Above mentioned aim can be reached by describing the process of the hardening and ensuring the optimum adhesive layer.

In this paper there are stated the results of the research focused on using the adhesive bonding technology as the way of bonding in the agricultural machinery construction and for bonding or prospectively for securing various additional materials showing increased wear resistance.

METHOD

On this presumption basis it was possible to follow up on research and conclusions published in contemporary scientific papers. The carrying out of tests according to the standard ČSN EN 1465 (1997) (adhesives – Determination of the tensile lap-shear strength of rigid-to-rigid bonded assemblies) is the basis of adhesive bonds laboratory testing.

The tests were carried out using the specimens from steel S235J0. The specimens in the size of strips were cut from the sheet panel of 1 x 2 m dimensions. The following list presents the identification of tested adhesives (two-component epoxy adhesive) which is used in text for better clear arrangement:

- Alteco 3-TON Clear epoxy adhesive F-05 **(A5)** – handling strength after 5 min.
- Alteco 3-TON Quick epoxy adhesive **(A4)** – handling strength after 4 min.
- Alteco 3-TON Epoxy adhesive **(A30)** – handling strength after 30 min.
- UHU plus schnell fest **(U5)** – handling strength after 5 min.

The bonded material surface was mechanically prepared by blasting of corundum grit F80 and chemically cleaned (Ra 1.88 ± 0.14 μm, Rz 12.47 ± 1.19 μm).

The bonding was carried out using the glass plates. The surface of one specimen was evenly coated with the adhesive in the designated part (12.5 mm). In this layer two distance wires of the relevant diameter 0.1 mm were inserted parallel to the load direction (Müller et al., 2007). The mixture of the resin and hardening agent was prepared according to the specific ratio (1:1). After the predetermined time (50, 100, 150 and 200% of handling time) the mixture was spread on the bonded specimen, the distance wires were imbedded, the second part of the bond was put on and the bond was fixed. The upper specimen was underlaid with the metal sheet of the same thickness (1.5 mm) and the specimens were set correctly according to the direct axis. Without delay after the application of the second specimen and the adjustment the bond was loaded using the weight of 720 g. This weight was determined on the basis of microscopic evaluation of the adhesive bond. The bond was left in the laboratory for the time described in the instructions for use at the temperature of 22 ± 2 °C (laboratory temperature). After hardening the destructive testing of the adhesive bond and the tests evaluation followed using the universal tensile strength testing machine.

After the adhesive bond destruction the maximum force was read, the lapping surface was measured according to the standard CSN EN 1465 and the adhesive bond strength was calculated (CSN EN 1465, 1997).

RESULTS AND DISCUSSION

Graphical presentation of results of the influence of the application and time fixation of the adhesive bonding mixture on the tensile shear strength of the adhesive bonds are visible in Fig. 1. The results show the significant fall of the tensile shear strength of the adhesive bond with increasing time needed for the adhesive bond creation.

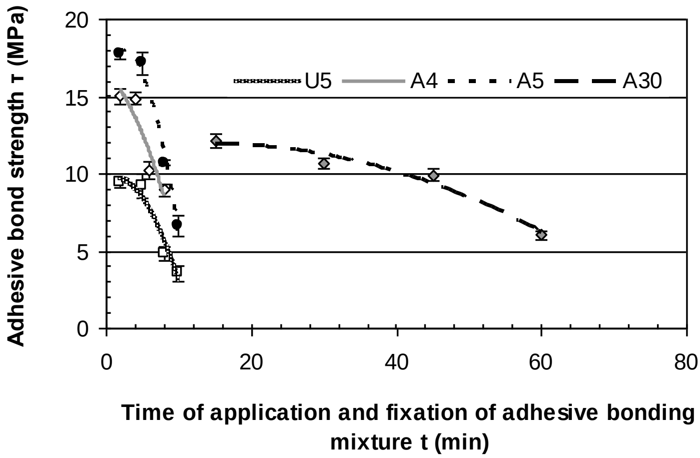

Figure 1. Influence of application and fixation of adhesive bonding mixture on adhesive bond strength.

From Figs 2 and 3 there are visible distinct differences in the mechanism of the failure area breaking which goes through various stages of the adhesive bonds hardening process. Fig. 2 shows the stage of the hardening process on reaching the handling strength at which the adhesive bond has not completely hardened. Fig. 3 presents the hardening process stage after reaching the adhesive bond's entire hardening.

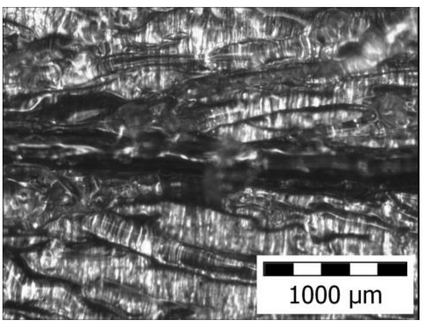

Figure 2. Failure area of adhesive bond after reaching handling strength.

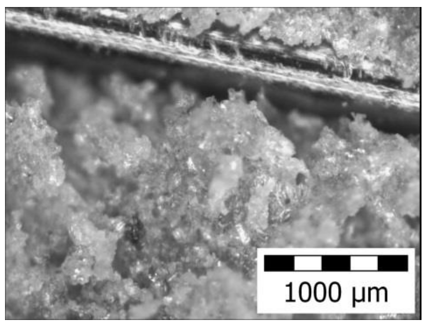

Figure 3. Failure area of destructive tested adhesive bond after reaching entire hardening.

For objective evaluation of the relation it is important to determine the dependence intensity. It is the task for the correlation analysis. The closeness of this relation is judged by means of the determination index, whose values can be from 0 to 1. When the values approach to 1, the relation is more intense. The closeness of the dependences among the adhesive bond strength and the application and parts fixation time is very high. By values introduction in equations presented in Table 1 it is possible to predict the further function course.

Table 1. Equations of regressional functions and their determination index

Adherent: Steel S235J0		
Adhesive	Functional equation	Determination index $I^2_{\tau t}$
A30	$\tau = -0.0028.t^2 + 0.0801.t + 11.325$	0.96
A5	$\tau = -0.1977.t^2 + 0.9168.t + 16.864$	0.99
A4	$\tau = -0.0694.t^2 – 0.4437.t + 16.577$	0.90
U5	$\tau = -0.0821.t^2 + 0.1675.t + 9.6671$	0.94

Tukey's HSD test was used for statistical comparison of mean values. Table 2 shows single means, there are not any statistically significant differences.

Table 2. Statistical comparison of mean values – Tukey's HSD test

Adhesives	Handling time * (%)	Arithmetical mean (MPa)	Agreement								
			1	2	3	4	5	6	7	8	9
U5	200	3.54	*								
U5	150	4.86		*							
A30	200	6.02		*	*						
A5	200	6.64			*						
A4	200	8.98				*					
U5	100	9.17				*	*				
U5	50	9.45				*	*				
A30	150	9.93				*	*	*			
A4	150	10.24					*	*			
A30	100	10.67						*			
A5	150	10.72						*			
A30	50	12.10							*		
A4	100	14.87								*	
A4	50	15.02								*	
A5	100	17.17									*
A5	50	17.70									*

*****Workability time before application and fixation of the adhesive bond related to the handling strength – published by the adhesive producer.

The tensile shear strength is in the workability time of the adhesive bonding mixture before the application and fixation of the adhesive bond related to the time of reaching the handling strength 50 and 100%. The strength in this time is the same at the adhesives A5, A4 and U5. At the adhesive A30 the sets are not statistically the same. From above mentioned results that at adhesives A5, A4 and U5 there are not more significant differences of reaching the workability time stated by the adhesive producer.

Another significant factor of the adhesive bond creation is the optimum adhesive layer thickness which influences the bond strength and the costs for the bond creation. From Fig. 4 the consequences of an unsuitable technological discipline at the adhesive bonds creations are visible.

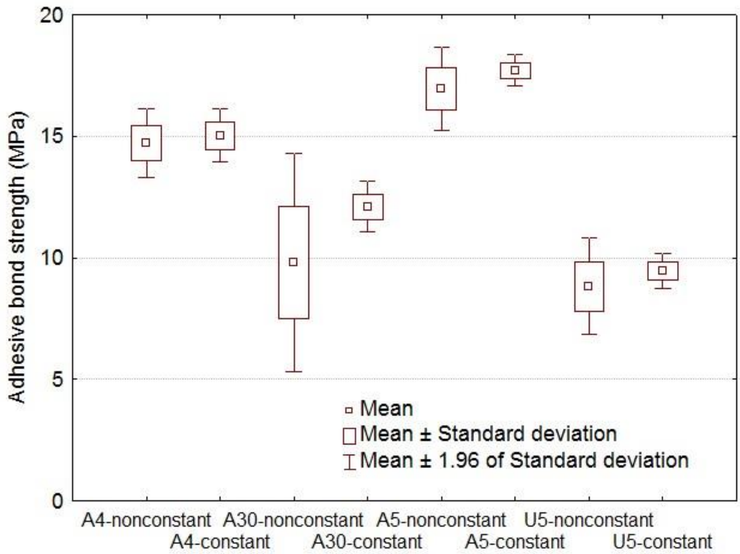

Figure 4. Influence of adhesive layer thickness uniformity on adhesive bond strength.

The unequal adhesive layer thickness affects negatively also the costs for the adhesive bond creation (Fig. 5). A similar negative influence on costs is the unsuitable set up of the adhesive dosing system at which the adhesive hardens during dosing on the adhesive bonded materials.

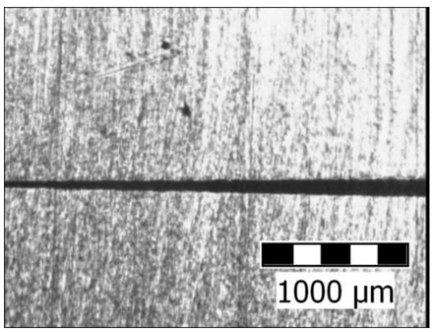

Figure 5. Adhesive bond cut - unequal adhesive layer.

The equal adhesive layer thickness belongs among the basic key criteria of the adhesive bond creation, which influence the adhesive bond strength (Messler, 2004; Kotusov, 2007; Grant et al., 2009). The results visible from Fig. 4 proved this fact.

Grant et al. (2009) stated in the conclusions of their experiments that the bending moment increases together with increasing layer thickness and the inequality. The bending moment proves to decrease the strength. It can be reconciled with these conclusions. Further the dispersion variance of the adhesive bond strength increases. For practical application it is an essential finding with a fundamental influence on safety.

CONCLUSION

From evaluated experiments the influence of the adhesive mixture workability and adhesive layer thickness on the resultant adhesive bond strength decrease is perceptible. For users of adhesives the information about the mixture workability is very important. The time between the adhesive application on the bonded surface and the following fixation can be very different. The user should have enough information about the time of the adhesive application. In industrial use of automatic dosing and applying devices it is all the time necessary to follow and check the continuity and the cycle time of the process. At the working stop also for an imponderable time it is necessary to take off the mixed adhesive from the applying device to prevent the decrease of the demanded bond strength. Considering when purchasing an adhesive, it would be suitable to buy such adhesive, which presents basic data and recommendations for use on the packaging. Adhesives without the relevant information on adhesive mixture workability time are effectively applicable only with inconveniences.

It is also very important after reaching the handling strength to prevent the manipulation of the bonds. In many cases the expressive failure of arising polymer chains would occur. This change is irreversible and the effect would be the deterioration of the qualitative characters of the adhesive bonds.

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