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Research of liquid contaminants influence on adhesive bond strength applied in agricultural machine construction

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Abstract. An adhesive bonding technology is a prospective bonding technology of diverse materials. Namely the research in the sphere of the degradation aspects affecting the adhesive bond during the technical life of the adhesive bonded complex is essential. Mineral and industrial fertilisers can be included as significant degradation agents.
The aim of the research was to find out the relevant knowledge in the sphere of the degradation of the adhesive bonds placed in the water bath, the oil bath and the solution of the mineral and industrial fertilisers. The experiment's results bring knowledge for producers of agricultural machines introducing adhesive bonding technology into their production programme. Two-component constructional epoxy adhesives were tested which were placed into the water bath, the oil bath and the solution of mineral and industrial fertilisers. Some agents caused such changes in the adhesive that the adhesive bond strength decreased to zero value already after 90 days. Significant changes of the adhesive bond strength occurred in the interval 15–45 days depending on the adhesive and agents. The strength decrease was connected with the change of a failure area from cohesive one to combined and then to adhesive one. The research showed that it came to diffuse seepage and to a partial corrosion of the adhesive bonded steel samples.

Key words: Bonding technology, degradation, fertilisers, fracture surface, oil, water.

INTRODUCTION

An adhesive bonding technology is a prospective bonding technology of diverse materials. For successful practical application pieces of knowledge are essential gained by studying factors which significantly influence mechanical properties of the adhesive bonds. The adhesive bonds lifetime depends on the environment to which they are exposed and the environment factors are much more variable and limited than in other bonding methods (Müller et al., 2009).

The adhesive bonds are influenced not only by the environment but also by definite degradation agents, in the case of the agricultural production, e.g. various fertilisers or technical fluids of agricultural machines. The example of the usage is the adhesive bonding of breakwater in agricultural fertiliser sprayer. Namely the research in the sphere of the degradation aspects affecting the adhesive bond during the technical life of the adhesive bonded complex is essential. Mineral and industrial fertilisers can be included as significant degradation agents.

Analysing the adhesive bond failure Messler (2004) found out that the operational environment leading to the adhesive degradation or to the degradation of the mutual interface adhesive – the adherent is another problem. To find out why the failure in the adhesive bond has occurred, if possible before anything else, is by observing the way in which the failure has come to light. Two basic failure mechanisms shown by the breaking of the adherent itself or the adhesive bond are distinguished. The adhesive bond failure shows up namely by the adhesive and cohesive failure. At the adhesive failure the weak place of the bond is the marginal layer between the adherent and the adhesive. Either the material is not suitable for the adhesive bonding or the adhesive bonded surface was polluted and the adhesive was totally separated from one of the adherent surfaces.

At the cohesive failure the adhesive is overborne with outside influences, e.g. the temperature, ageing, etc. (the failure area goes through the adhesive).

Doyle & Pethrick (2009) and Sargent (2005) claim that the environment changes can affect both the way in which the adhesive physical properties change in time, and the strength of the interface between the adhesive and the adherent.

The exposure of the adhesive bonds to water, extreme temperatures or chemicals can affect the process of the bond failure by weakening the interface of the adhesive and/or the bond (Nolting et al., 2008).

Authors (Abel Wahab et al., 2002; O´Brien et al., 2003; Liljedahl et al., 2009) found out that moisture leakage can be faster at the interface adhesive – adherent. This results in that the content of the real moisture in the adhesive layer is not entirely decisive. Authors who dealt only with the moisture leaking into the adhesive overestimated the general view on the adhesive bond (Liljedahl at al., 2009). So, also the change of the failure area from the cohesive to adhesive one can be assumed.

Bonds which were not dipped into the bath showed the cohesive failure, that is in the adhesive. Bonds dipped into the bath failed in a combined way, in the interface the adhesive failure occurred in edges whereas the cohesive failure was in the middle. Liljedahl (2007) solved the same issue and he found out that during a longer time, that is since 50th day till the end of the measured interval 350th day of the exposure to a humid environment, the percentage proportion of the adhesive failure increased from about 60% to 80% whereas the samples tested under dry conditions showed approximately the same adhesive failure of about 40%.

Authors (Kinloch, 1983; Comyn et al., 1997; Josbi et al., 1997; Figione et al., 2006) state in their researches that liquid contaminants such as fuels, fertilisers and non-freezing liquids have similar trends, which also attack the link adhesive – adherent and destroy the bond integrity. Also other chemical agents (degreasers) can affect the bond and the adhesive bonds sometimes resist ca. 30 days (Sonawala & Spontak, 1996). This is the problematic factor of the adhesive bonding technology from the user’s point of view.

Bálková et al. (2002) tested the strength of adhesive bond dipped into the water bath when the adhesive bond strength decreased already after 10 days of the exposure to the water bath. The longer the bonds were exposed to the water bath, the weaker the link in the bond was. The adhesive failure of the adhesive bond prevailed in these tests. On the contrary, the adhesive bonds exposed to the ageing process under the laboratory conditions showed cohesive failures from almost 60%.

METHOD

Experiments were made according to the standard CSN EN 1465, which determines the tensile lap-shear strength of rigid-to-rigid bonded assemblies. The substance of the test is the determination of the maximum force, which acts parallel with the bonded surface and with the principal axis of the assembly until the failure. This method corresponds to operational stress. The measured force at the adhesive bond failure is the test result. The testing samples are prepared by bonding of two adherents of dimensions 100 ± 0.25 x 25 ± 0.25 x 1.6 ± 0.1 mm. The specific overlapping is 12.5 ± 0.25 mm (ČSN EN 1465, 1997). Laboratory tests were carried out using the standardised testing samples made according to the standard CSN EN 1465 from the constructional plain carbon steel S235J0.

Before bonding the surface of bonded samples was blasted using the Al_2O_3 of F24 grain size. Using the profilograph Surftest 301 the following values were determined: Ra 2.4 μm, Rz 15.3 μm and Rt 20.2 μm.

For bonding the two-component epoxy adhesives: BISON EPOXY METAL (BM), BISON epoxy universal (BU), ALTECO 3-TON epoxy adhesive (A30) were used.

On one sample the adhesive was applied so that the whole surface in designated length (12.5 mm) was evenly coated. In this layer two distance wires of 110 μm diameter were placed. The distance wires were laid down parallel to the load force direction of the tensile strength test. The assessment was left in the laboratory for the instructed determined time (24 hours) for curing at the temperature of 22 ± 2 °C (temperature in the laboratory).

Adhesive bonds strength values influenced by degradation mediums which occur in agriculture were compared with values measured under laboratory conditions. Two-component constructional epoxy adhesives were tested which were placed into the water bath, the oil bath and the solution of mineral and industrial fertilisers.

Running degradation processes were evaluated after determined time intervals. The time among single intervals was 15 days starting from the day of total curing. The last measuring was carried out after 90 days in the degradation medium until the strength occurred under the measurable range.

After curing, the marking of single samples and placing in the relevant medium followed. As degradation mediums water bath, slurry, fertiliser DAM and diesel oil were used.

Each cycle was finished by the destructive testing of bonded joints using the universal tensile-strength testing machine. After the joint rupture the maximal force was read, the overlapping length was measured with an accuracy of 0.05 mm and the rupture type was determined according to ISO 10365 (1995).

RESULTS AND DISCUSSION

From determined strength results of adhesive bond BM, BU and A30 it is evident the different influence of various degradation environments related to the time interval of affecting the adhesive bond strength (Fig. 1 till Fig. 5). When comparing the curve representing the exposure of the adhesive bonds to the laboratory conditions and other curves of exposure to the degradation environments it is clear the huge danger of the action of the degradation environment to resultant decrease of the strength values. This dangerous phenomenon should lead to the prevention/elimination of the access of the above mentioned degradation environments to adhesive bonds, prospectively to a limitation of the time of their action.

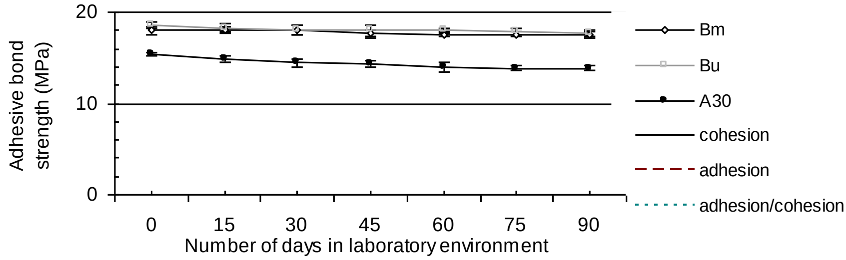

Figure 1. Influence of laboratory environment on adhesive bond strength.

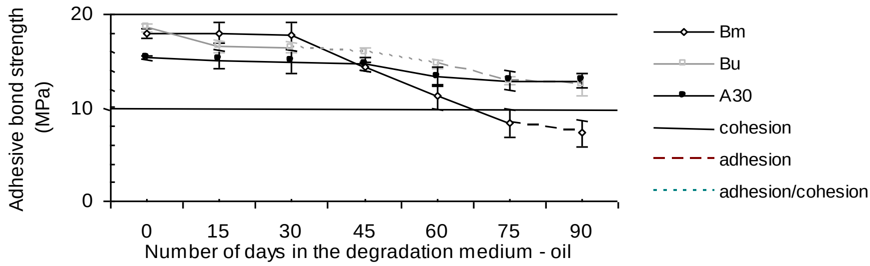

Figure 2. Influence of degradation environment on adhesive bond strength.

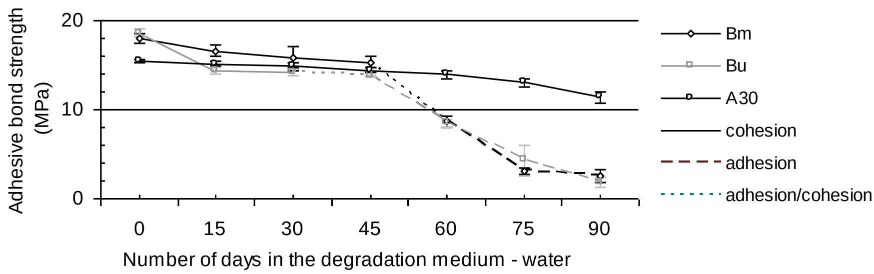

Figure 3. Influence of degradation environment on adhesive bond strength.

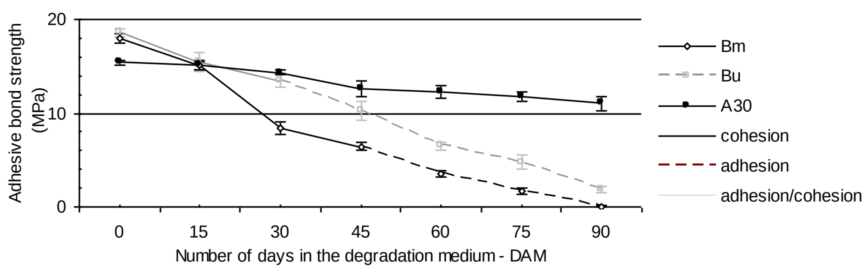

Figure 4. Influence of degradation environment on adhesive bond strength.

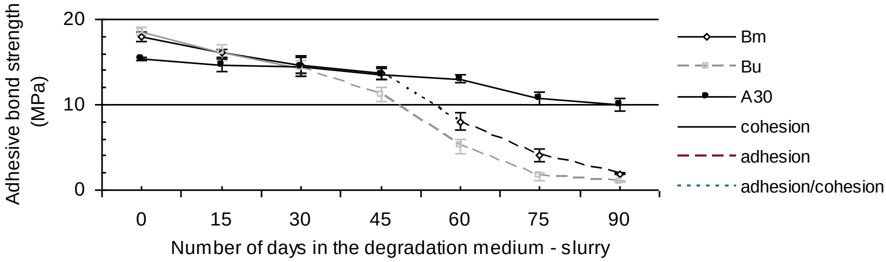

Figure 5. Influence of degradation environment on adhesive bond strength.

Common attribute of degradation environments (except laboratory conditions) is, however, a considerable decrease of the bond strength according to the course of curves. Failure areas of destroyed adhesive bonds placed in four degradation environments showed various types of failure. In the first phase they showed identically the cohesive failure area, prospectively the special – cohesive failure. Further, the failure type changed depending on the degradation environment. When identifying the adhesive failure also the undercorrosion of the adhesive layer was often discovered and so the adhesive strength was also decreased at the same time. Fig. 6 shows an example of undercorrosion of the adhesive layer and the diffuse seepage.

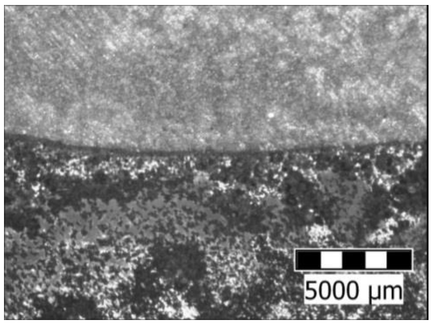

Figure 6. Diffuse seepage and undercorrosion of the layer of adhesive BU (upper part – adhesive, bottom part – corrosion and diffuse seepage of contaminants).

The previous finding offers an explanation of a rapid fall of the adhesive bond strength. Another cause influencing the adhesive bond strength decrease is the diffuse seepage of the degradation medium into the adhesive bond. The functional area that is the overlapping area was constantly lessened by this and so came the rapid fall of the adhesive bond strength (Fig. 7). And not only the decrease of the cohesive strength by the diffusion of the moisture and chemical agent into the adhesive bonds, but also the decrease of the adhesive adhesion.

On the basis of the evaluation of carried out experiments it can be said that the resultant adhesive bond strength decreases during the time interacting with the environment. The measure of the strength fall depends on the specific conditions of the environment.

The experimental results found out in four different environments/mediums confirm the statements of Kinloch (1987) and Court et al. (2001) about negative and harmful effects which the environment can have on the adhesive bond.

Under the laboratory conditions the average strength fall of the bonds adhesive bonded by all used adhesives was found to be 5.61% after 90 days. The strength fall was more considerable at four other degradation mediums, namely at the adhesives BM and BU. Often the adhesive bond strength decreased to almost zero value after 90 days. At the adhesive A30 the strength decrease also occurred but it was not so considerable. The adhesive A30 proved its relative high resistance to various environments/mediums compared with the adhesives BM and BU. Conclusions released by Crocombe (1997) that the adhesive bond degradation depends on the adhesive type and on the degradation environment were confirmed by these experiments. This knowledge can be fully used in the elimination of the negative influence of the relevant environment.

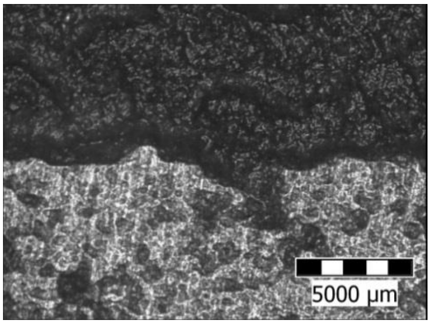

Figure 7. Diffuse seepage of oil in layer of adhesive BM (dark part – diffuse seepage into layer of adhesive).

From the results it is visible that the corrosion of the adhesive bonded materials (adherents) is not in most cases such a definite factor having influence on the adhesive bond strength. However, the presumption was confirmed that the adherent corrosion can cause undercorrosion of the adhesive bond and so it causes the change of the cohesive failure to adhesive one secondarily decreasing the adhesive bond strength. Messler (2004) came to a similar conclusion when he states that in most cases the corrosion in the adherent or along the interface adhesive – adherent contributes to the bond degradation and to connected strength fall. Examples of this statement are the adhesive bonds placed in the diesel oil bath. This medium was distinguished for minimum corrosion but for huge strength losses regarding the time of placing.

The change of the failure type is also caused by the diffusion of the moisture and given medium (namely its chemical stuff) into the adhesive. The functional area that is the overlapping area is constantly decreased by it so it comes to the rapid decrease of the cohesive strength. By decreasing own cohesive strength and by decreasing the adhesion it comes inevitably to the destruction in the interface adhesive – adherent which is shown by the adhesive failure area. These conclusions are supported by the researches of Armstrong (1997) and Kinloch & Osiyemi (1993) who state that the main cause of the failure of the bond service life is the degradation of the interface between the adhesive and the adherent distinguished for the cohesive failure.

The main change sets in from the cohesive failure, either in the adhesive or adherent, to the interface failure that is the adhesive one (Amstrong, 1997). Above stated theory was confirmed by destroyed adhesive bonds.

Adhesive bonds (adhesives BM, BU and A30) placed under the laboratory conditions showed always the cohesive failure area after the destruction and the strength fall noticeably lower than the adhesive bonds placed in other environments. Bonds adhesive bonded by the adhesives BM and BU placed in the water bath, in the diesel oil bath, in the mineral and industrial fertilisers showed the change of the failure area from the cohesive one to the adhesive/cohesive one and gradually to the dominant till exclusive representation of the adhesive failure after the destruction in different time interval. This change showed itself with the adhesive bond strength fall, too.

CONCLUSION

Various mediums affecting the adhesive bond strength in given time interval were distinguished for negative effects. Environments/mediums acting on the adhesive bonds are a significant part having influence on the long-term quality and the strength of adhesive bonds. Often it can come to spontaneous destruction during the adhesive bonded parts loading after a very short time during which these parts will be exposed to the degradation mediums. This dangerous phenomenon should lead to the prevention/elimination of the access of above mentioned degradation environments to the adhesive bonds, prospectively to the restriction of the time of their action.

From reached strength results of the bonds adhesive bonded by the adhesive A30 lower influence of tested degradation mediums is visible compared with the adhesives BM and BU.

Some agents caused such changes in the adhesive that the adhesive bond strength decreased to zero value already after 90 days.

Significant changes of the adhesive bond strength occurred in the interval 15–45 days depending on the adhesive and agents. The strength decrease was connected with the change of a failure area from cohesive one to combined and then to adhesive one. The research showed that it came to diffuse seepage and to a partial corrosion of the adhesive bonded steel samples.

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