MODERN TECHNOLOGY OF BONDING METAL SHEETS – TECHNOLOGIC QUALITIES OF ADHESIVE BONDS

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Abstract. A common attribute of production companies is a requirement for bond creation. An adhesive bonding technology is a prospective bonding technology of diverse materials. For successful practical application pieces of knowledge are essential gained by studying the factors which significantly influence the mechanical properties of the adhesive bonds. The adhesive bond rise is influenced by a rise of chemical – physical bonds. When applying the adhesive bonding technology it is necessary to characterize prospective limits occurring during the application in the given environment, namely a degradation process of the adhesive in a hardened state. The aim of the research is to create the adhesive bond which provides the maximum strength and the quality possible for single combination of the adhesive and adherents, usually at minimum costs. The above mentioned fact is possible to be achieved by describing the behaviour process of the adhesive itself. The published results aim to know the degradation processes in the adhesive and they come out from the standard ČSN EN 9142. On the base of the carried out experiments it can be said that the resultant adhesive strength is decreasing in time during the environment influence.

Keywords: agricultural machine, bonding technology, constructional adhesive, cyclic degradation.

Introduction

Differences of the production process have usually in the particular industrial sectors one common element that is dividing and joining material [1]. Another common element in almost all industrial sectors is considering the following attributes: simplicity and efficiency of the production process. It is also correlative of constant improvement and searching for new technologies which simplify the production process. This assumption gives access to prospects in the field for cutting and joining sheet metal. This is one of the basic steps required to ensure the competitiveness of the products on the global market. In the production proper choice of the joining method is one of the possible ways of implementation of the prospective methods. In this case it is possible to characterize three basic methods of connecting, namely, mechanically, thermally and chemically. The application of the specific components of the joining technology requires knowledge of their technological principles that affect the quality characteristics of the final bond.

Contemporary conclusions from the practice are distinguished for primary distrust in the adhesive bonding 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 the creation of which and following usage are influenced and also limited by many partial factors. The experimental research of the partial factors and their simulation are important milestones in a possibility to specify the optimum values of the adhesive bond ensuring the construction reliability and not increasing the economic costs for production at the same time.

Adhesive bonding is one of a number of material joining methods, which allows creating bonds with various shapes and properties that are not possible to be achieved by "classical" methods [2; 3].

The aim of the adhesive bonding process is to create a bond that provides maximum strength and quality which is possible for individual combination of adhesives and adherents, usually with low cost. To achieve this aim some of the key requirements as following have to be met:

- A proper surface preparation and a cleanliness of an adherent before applying adhesive, to ensure wetting of the adherent surface by the adhesive;
- A proper choice of the adhesive for specific adherent types and prevailing conditions of use;
- To ensure a constant adhesive layer;
- To take into account the environmental factor effects on adhesive bonds [1-4].

When the adhesive bonding theory and the related mechanism of the adhesive bond cohesion are applied, the question about the interaction between the adhesion, the adhesive wettability and the cohesion itself, which significantly affect the final strength of the bond, comes out [1; 2]. In the respect of the internal structure it is possible to consider each adhesive bond to be a complex of three main layers, namely: bonded material, adhesive and cohesive layer. Research activities are focused mainly on the evaluation of adhesive bonds. Nevertheless, the behaviour of the adhesive itself is significant in the practical application. The reason is a description of principles and the dependence of mechanical changes of the adhesive itself, which are impossible in the interaction with the adherent. Adherents have different mechanical and physical properties (e.g., corrosion), which have a significant impact on the final adhesive bond.

Messler found out the causes of the bond failure in the adhesive bonds by analysis of the adhesive bond failure and divided the failures into five major categories:

- The adhesive is not compatible to the adherent;
- Insufficient adhesive bonded surface preparation;
- Internal stresses in the adherent;
- Processing errors;
- Operating environments leading to degradation of the adhesive or mutual boundary of the adhesive – adherent [2].

The above mentioned facts show that 70 % of the causes of failure in adhesive bonds are affected by the adherent. The adhesive is dependent especially on the correct mixing ratio and time to create a bond (processing errors). Operating environments are another important fact, which is often the dominant element in the cause of the bond failure.

It is important to analyse the specific conditions of degradation, which will affect the bond during the whole or particular life of a durability, to determine specific limits of the adhesive bonding technology application [5]. The degradation processes are globally responsible for material and economical losses. Especially it is specific degradation media, which is in the certain area of the human activity [6]. Specific environment is, for example, in the agricultural, forestry and municipal sectors. There is currently unavailable technique how to create a bond, which can predict the environmental degradation of adhesive bonds. Most of the experiences about the determination of the bond failure come from the research of the mechanical characteristics and fracture surface(s) after the bond failure.

Adhesive bonds which are exposed to "natural environment" conditions, are attacked by many factors of degradation, there is standing out the effect of heat, moisture, atmospheric oxygen, ozone and microorganisms [6]. The degradation process makes a cleavage in some macromolecular substances to low-molecular product, possibly to the monomer, without change of its chemical composition, that is depolymerize. Another case is when the low-molecular particles are cleaved thereby the chemical structure is changed, i.e., destruction of bond / adhesive. The destruction may occur especially in the final stage of the process with emergence of the cross links between the chains. In all of these cases the polymer is degraded [6].

The aim of the experiment was laboratory control of the mechanical properties of structural adhesive by world leading manufacture of two-component epoxy resins system and its dependence on the cyclic degradation process.

Materials and methods

The specimens, in the form of casting from structural two-component epoxy adhesives, were the subject of the research. The test specimens had the basic shape and size defined by ČSN EN ISO 3167 (Plastics – Multipurpose test specimen) [7]. Moulds for casting the test specimens had been made of Lukopren N with the use of the prepared steel models (Figure 1). The application of the prepared two-component structural adhesive to the module was made by means of the syringe forms of a volume 20 ml. The degradation processes of the specimens were related to the environment and time. The specimens were subjected to the degradation process according to ČSN EN ISO 9142 [8].

In the framework of the experiments focused on the effect of the environmental degradation, the specimens were exposed to a cyclic operation of immersion in water and water with mineral chloride less fertilizer NPK (Cererit) with sulphur, magnesium and trace elements (boron, molybdenum, copper and zinc), 33 % solution of road salt and rain water, diesel oil.

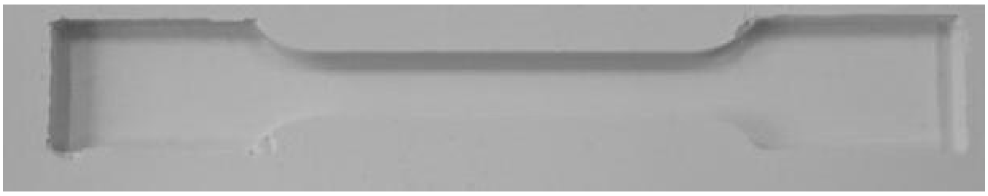

Fig. 1. **Mould for casting the test specimens**

The specimens were tested in the cycles according to ČSN EN ISO 9142 consisting in application of the cycle D5 (cycles: hot-dry, hot-humid and cooling), i.e., 48 ± 1 h in the conditioning chamber at 55 ± 2 ℃, 48 ± 1 h immersion in degradation medium, 24 ± 1 h cooling chamber at temperature of -20 ± 2 ℃, 48 ± 1 h immersion in degradation medium [8]. The specimens were exposed to 0, 1, 2, 4, 6 and 10 cycles of the test. The testing cycle contained 10 testing specimens which were subsequently destructive tested.

Destructive tests, which are necessary to determine the tensile properties according to ČSN EN ISO 527-1 (Plastics – Determination of tensile properties – Part 1: The basic principles) [9], were conducted after the finish of the test cycle. The tensile strength σ_M was determined by the destructive test. Calculation of the tensile strength σ_M was performed according to the formula (1).

$$\sigma_M = \frac{F}{A} \tag{1}$$

where σ_M – Ultimate tensile strength, MPa;
F – Measured value of force, N;
A – Original cross sectional area of the specimen (wide × thickness), mm^2.

Results and discussion

The common feature of the degradation environment is according to the results marked decrease of the tensile strength of the adhesives, as it can be seen in Figure 2. The variation coefficient ranged in the interval 4.1 – 5.43 % in single testing cycles. The water bath was distinguished for the variation coefficient 4.1 %, the solution of salt and water 4.51 %, diesel oil 5.43 % and the fertilizer Cererit 4.62 %. The value 10 % stated by the standard was not exceeded in any testing set.

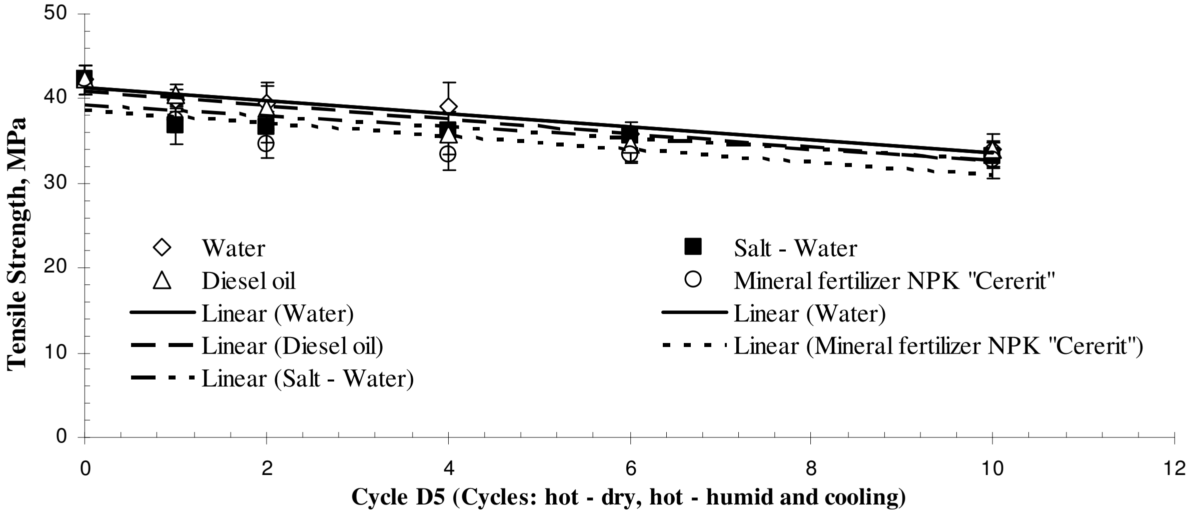

Fig. 2. **Effect of environment degradation on tensile strength of adhesive**

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, the values of which can be from 0 to 1. When the values approach 1, the relation is more intense. The closeness of the dependences among the adhesive bond strength and applying, and parts fixation time is very high. By the value introduction in equations presented in "Table 1" it is possible to predict the further function course.

The Tukey HSD test was used to compare the statistical measured data sets. The pertinence of each average value to statistically homogeneous groups can be seen in "Table 2", i.e., there are no statistically significant differences at a significance level of $\alpha = 0.95$ among the data sets.

Table 1

Equations of regressional functions and their determination index

Environment	Function equation	Determination index $R^2_{\sigma_M x}$
Mineral fertilizer "Cererit"	$\sigma_M = -0.755x + 38.564$	0.60
Diesel oil	$\sigma_M = -0.8299x + 40.845$	0.85
Salt - water	$\sigma_M = -0.6579x + 39.332$	0.68
Water	$\sigma_M = -0.7705x + 41.39$	0.93

Table 2

Statistical comparison of two sets of data - Tukey HSD test

Environment	Arithmetical mean (MPa)	Agreement	
		1	2
Mineral fertilizer	35.67	****	-
Salt - water	36.81	****	****
Diesel oil	37.66	****	****
Water	38.44	-	****

A diffuse infiltration of the degradation media into the specimens was determined from the fracture surface. The diffuse infiltration was also confirmed owing to the change of the colour of the originally transparent specimens, especially in the mineral fertilizer and rain water with road salt. The results were compared with comparing standard "0 day exposure" and a quick decrease of the tensile strength of the adhesive was found out.

The tension diagram confirms the assumption that the adhesive (thermosetting) shows that neither adhesive nor adhesive bond have distinct strength, see "Figure 3". The above mentioned facts lead to the conclusion that the adhesive bond also in the interaction with the material has similar behaviour as the adhesive itself. The strength values cannot be compared, owing to the deformation of the adherent, i.e., carbon steel S235J0. In the case of the adhesive there is a tensile stress (according to ČSN EN ISO 527-1). In the adhesive bond there is the combination of the tensile and shear stress (according to ČSN EN 1465).

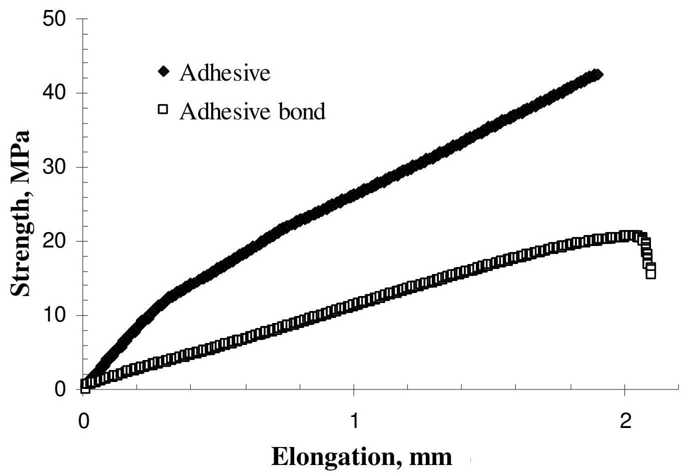

Fig. 3. **Tension diagram of adhesive and adhesive bond**

Conclusion

Environment / media in which the adhesive bonds act are an important element which affects the long-term quality and strength of the adhesive. Degradation processes of the operating environment operate on the adhesive. In the case of adhesive bonds it is important to consider the interaction between the adherent and adhesive, especially adherent has a negative synergic effect. The degradation process is amplified by other factors of the bonded material when the operating environment affects the adhesive bond. The main reason is corrosion, which leads to a deterioration of the adhesion ability. Often it is possible to meet the spontaneous destruction of adhesive bonds after very short time, when the adhesive bonds are exposed to the degradation medium. This dangerous phenomenon should lead to the prevention / elimination of the environmental degradation access of the showed adhesive bonds, or reduction of the exposure time.

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