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# INFLUENCE OF DESTINATION AT ADHESIVE BOND PRODUCTION ON ITS STRENGTH

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**Abstract**

The manufacturing process running at various countries at present, these differ from each other in particular climatic condition influencing the production technology. This paper is focused on the analysis of steel adhesive bonds produced in Central Europe (Czech Republic) and in the province of North Sumatra (Indonesia). The aim of the research was to evaluate the strength of adhesive bonds produced in Central Europe and Indonesia (North Sumatra). The second aim was evaluate the effect of adhesive bonded surface treatment.

The results of the experiment confirmed a clear positive or negative trend between places of creation the bond for two-component epoxy. The positive effect was reflected in Central Europe (Czech Republic) on the creation of cyanoacrylates adhesive bond. There were no effects of the adhesive bond creation to change the failure area.

**Key words:** adhesive bonding technology, Central Europe, North Sumatra, AlCu4Mg, adhesive bond strength.

## INTRODUCTION

The adhesive bonding technology is a prospective method of bonding of diverse materials, when bonds between adhesively bonded material and adhesive itself arise (MÜLLER, 2016; MÜLLER & HERÁK, 2013).

The adhesive bonding technology is cheap and quick method of bonding, which is utilized in almost all fields (PEREIRA ET AL., 2010; MÜLLER 2015B). Bonding of aluminium and its alloys was introduced in England in the 1940's.

The adhesive bonding technology depends on the adhesion of the adhesive to the adhesive bonded surface, on wettability of adhesive bonded surface and on the cohesion that means on own strength of the adhesive (MÜLLER, 2016).

The adhesive bond is the complex of three layers – adhesive bonded material (called adherent), adhesive layer and cohesive layer.

All three layers are significantly influenced for example by the surface treatment, environment etc.

GERALD, PETHRICK (2009) AND SARGENT (2005) ascertained the influence of the environment on a change of physical properties of adhesives. Namely, it was the adhesive bond strength.

A large part of industrial production is currently being transferred to the development countries and areas. These countries have quite different geographical, climatic, and technological conditions than are those found in the countries in which such production import is the aim. In the equatorial countries the usage of bonded joints is increasing, mainly in the automobile and naval industries as well as in the agricultural machines and tools production and, last but not least, in the production of daily use devices (HERÁK ET AL., 2009).

Polymeric materials in its practical use are almost never exposed to only one factor. It is usually a combination according to the climatic conditions. Influence of atmosphere on the adhesive used is given mainly by the simultaneous action of four basic factors. These factors include temperature, water and its vapors, oxygen and ultraviolet radiation (HU ET AL., 2013; COMYN, 1983; OUDAD, 2012).

LOH A CROCOMBE (2002) given as the most common factor causing failure of the adhesive bond at the interface of the adhesive / adherend exposure of such a joint combination of increased humidity and temperature.

The atmosphere has an effect the adhesive bonds cyclical character. We define daily, seasonal cycles, cycles associated with changes in weather etc. This action of the atmosphere generated thermal and moisture stress cyclical character of the adhesive bonded joints. The faster turns, the faster fatigue occurs connections, which limits its life.

Acting of changeable moisten, which often happens under atmospherics conditions, can be even more dangerous. Tensions mentioned above gain the cyclic features, which significantly increases destruction process. Methods of accelerated aging are based on this effect (COMYN, 1983; MÜLLER, 2016).

Environmental influences applied to adhesive not only in the formation of the bond, as well as during

transport and storage, for example du to direct solar radiation, solar radiation (MÜLLER & VALÁŠEK, 2014A).
Considerable part of the research on single-lap adhesive bonds is focused on geometrical design of adhesive bonds, thickness of adhesive layer and on mechanical properties of adherents (MÜLLER ET. AL., 2010; MÜLLER & VALÁŠEK, 2013).
The aim of the research was to evaluate the strength of adhesive bonds produced in Central Europe and Indonesia (North Sumatra). The second aim was evaluate the effect of adhesive bonded surface treatment.

## MATERIALS AND METHODS

Adhesive bonds and process of testing the adhesive bonds was in accordance with standard ČSN EN 1465. The basis of adhesive bonds laboratory testing was the determination of the tensile lap-shear strength of rigid-to-rigid bonded assemblies according to the standard ČSN EN 1465. Laboratory tests of the adhesive bonds were performed using the standard test specimens made according to the standard CSN EN 1465 (dimensions 100 ± 0.25 x 25 ± 0.25 x 1.5 ± 0.1 mm and lapped length of 12.5 ± 0.25 mm) from duralumin AlCu4Mg. Treatment surface is showed in the Tab. 1.
Three kinds of structural epoxy adhesives were used for this experiment. In Tab. 1 are showed the used adhesives, surface treatment and sign type of experiment.

**Tab. 1. –** Characteristics used adhesives and surface treatment

| Adhesive | Type | Sign | Treatment surface |
|---|---|---|---|
| loctite super bond | cyanoacrylates | LSB-WT | Without mechanical and chemical treatment AlCu4Mg |
| 3-ton quick | two-component epoxy | 3TQ-WT | |
| 3-ton epoxy | two-component epoxy | 3TE-WT | |
| loctite super bond | cyanoacrylates | LSB-GU | Mechanical treatment by abrasive cloth of grit P220 (at right angles to the loading force in the destruction of the adhesive bond) and without chemical treatment AlCu4Mg |
| 3-ton quick | two-component epoxy | 3TQ-GU | |
| 3-ton epoxy | two-component epoxy | 3TE-GU | |
| loctite super bond | cyanoacrylates | LSB-GP | Mechanical treatment by abrasive cloth of grit P220 (parallel to the loading force in the destruction of the adhesive bond) and without chemical treatment AlCu4Mg |
| 3-ton quick | two-component epoxy | 3TQ-GP | |
| 3-ton epoxy | two-component epoxy | 3TE-GP | |

Chemical composition of test alloy AlCu4Mg detected by spectral analysis is given in Tab. 2. This is a construction material suitable for components and construction elements of aircraft, railway carriages, agricultural machines, automobiles and other vehicles.

**Tab. 2. –** Chemical composition (mass %)

| Element | Al | Cu | Mg | Mn | Fe | Ti | Si | Zn |
|---|---|---|---|---|---|---|---|---|
| AlCu4Mg - ČSN 42 4201 | 93.2 | 5.01 | 0.57 | 0.51 | 0.31 | 0.01 | 0.35 | 0.02 |

On the surface of bonded adherents roughness parameters Ra and Rz were measured. Roughness parameters were measured with a portable profilometer Mitutoyo Surftest 301. Limit wavelength cut-off was set as 0.8 mm.
An even thickness of the adhesive layer was reached by a constant pressure 0.5 MPa. The lapping was according to the standard 12.5 ± 0.25 mm.
Specification of the environment where adhesive bonds was created:

In the experimental part the environment of Central Europe is marked with "CE-CZ", Indonesia, North Sumatra is marked with "NS-I".

- **Prague, CZ, Central Europe** is situated in the mild climatic zone of the northern hemisphere. It is the transition zone. Warm summer with rainfalls alternates with winter with lasting snow cover. Europe is especially characteristic by industrial production, which is exported all around the world. But at the present time this influence goes missing (MÜLLER ET. AL., 2013). Adhesive bonds were create in the laboratory characterized the constant temperature of 22 ± 2 °C and relative humidity 50 ± 5%.
- **Indonesia, North Sumatra, region Balige** is of tropical climate, which is during the whole year without fluctuations. The division into classic times of the year does not exist here. The division is related to the dryness and rainy seasons (MÜLLER ET. AL., 2013; HERÁK ET. AL., 2009). The average air humidity ranges from 70 to 100%. Region Balige - elevation 900 m, average daily temperature of 25 °C, relative humidity 80%. Adhesive bonds were create in the laboratory characterized the constant temperature of 26 ± 2 °C and relative humidity 95 ± 5%.

Adhesive bonds and bended materials (adherent) were packed in Indonesia and airlifted to CZ. There were destructively tested.

It can be assumed that the impurities on the surface of the bonded material greatly reduce the overall strength of the adhesive bond. A similar incidence of dust contaminants can be expected after mechanical surface treatment. The volume of impurities was determined by weighing (Scales Kern). The test specimens were weighed before and after chemical cleaning in a bath of acetone.

Laboratory tests were performed using the universal tensile strength testing machine LABTest 5.50ST (a sensing unit AST type KAF 50 kN, an evaluating software Test&Motion). The failure type according to ISO 10365 was determined at the adhesive bonds. The loading speed at the static test of the adhesive bond strength was always set as 10 $mm.min^{-1}$.

The results of measuring were statistically analysed. Statistical hypotheses were also tested at measured sets of data by means of the program STATISTICA. A validity of the zero hypothesis ($H_0$) shows that there is no statistically significant difference ($p > 0.05$) among tested sets of data. On the contrary, the hypothesis $H_1$ denies the zero hypothesis and it says that there is a statistically significant difference among tested sets of data or a dependence among variables ($p < 0.05$).

## RESULTS AND DISCUSSION

Significance of bonding surface modification has been demonstrated in many studies. Development of adhesives, however, aims to minimize the factors affecting the preparation of bonding surface. This trend is particularly pronounced in establishments, where the automatic production is introduced (MÜLLER & VALÁŠEK, 2013; MÜLLER, 2013, 2014).

Determination of volume of pollution on specimens intended for adhesive bonding was v CE-CZ cca 2.13 mg a v NS-I 1.01 mg.

The results show that the test specimens without chemical modification of bonding surface contained a considerable amount of impurities on their surface.

The surface roughness of the adhesive bonded material AlCu4Mg after mechanical treatment by abrasive cloth of grit P220 was Ra 1.08 ± 0.15 μm, Rz 7.38 ± 0.99 μm and without mechanical treatment was Ra 0.38 ± 0.07 μm, Rz 2.48 ± 0.43 μm.

Results of the adhesive bond strength are visible from Fig. 1.

Results of ANOVA F-test are following:

- In terms of statistical test (T-test, $\alpha = 0.05$) influence of different modification on bonded surface of AlCu4Mg is possible to state that the different surface treatments are statistically inhomogeneous groups. Hypothesis $H_0$ was not confirmed, i.e. there is a difference in the strength of the adhesive bond between the different types of experiments, i.e. various adhesives and place of bond creation NS-I and CE-E.in the significance level of 0.05. Statistical parameter $p = 0.0000$ was on all tested groups. A statistical comparison of the values shows that treatment bonded surface has an influence on adhesive bond strength.
- In terms of statistical test (T-test, $\alpha = 0.05$) influence the type of adhesive LSB, 3TE and 3TQ is possible to state that each adhesive are statistically inhomogeneous groups. Hypothesis $H_0$ was not confirmed, i.e. there is a difference between the each types of experiments, i.e. various place of bond creation NS-I and CE-E in the significance level of 0.05. Statistical parameter $p = 0.0000$ was

on all tested groups. A statistical comparison of the values shows that type of adhesive has an influence on adhesive bond strength.

- In terms of statistical test (T-test, $\alpha = 0.05$) influence the place of bond creation NS-I a CE-CZ is possible to state that the regions of bond creation are statistically inhomogeneous groups. Hypothesis $H_0$ was not confirmed, i.e. there is a difference between the each types of experiments, i.e. treatment surfaces and various place of bond creation i.e. NS-I and CE-E in the significance level of 0.05. Statistical parameter p = 0.0000 was on all tested groups. A statistical comparison of the values shows that type of adhesive has an influence on adhesive bond strength.
- Statistical comparison (T-test $\alpha = 0.05$) influence the place of bonding, i.e. the NS-I and CE-E on the adhesive bond strength is showed in Tab. 3. From a statistical comparison of the values shows that place of bonding has an influence on adhesive bond strength.

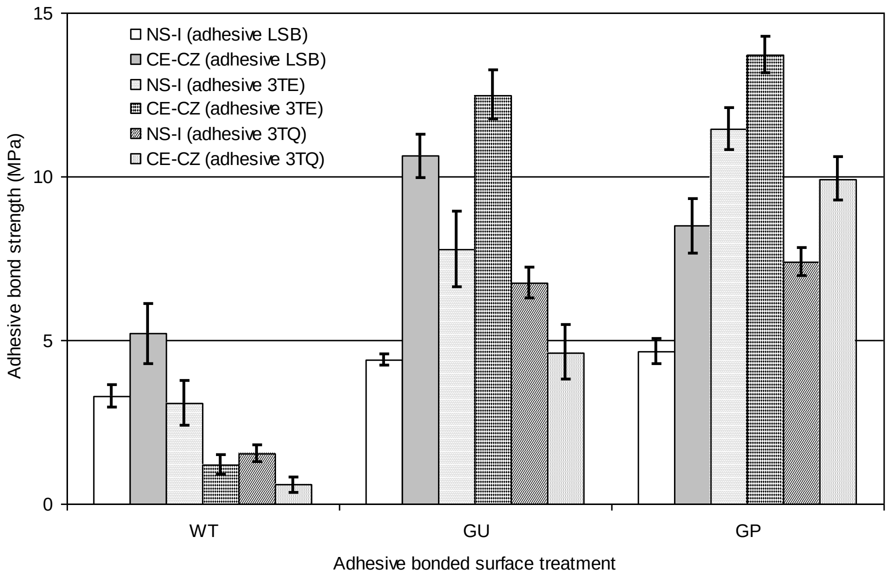


**Fig. 1. –** Results of the adhesive bond strength

**Tab. 3. –** Statistical comparison of place where adhesive bond was created NS-I and CE-CZ on adhesive bond strength (T-test)

| Sign | $H_0$: (p>0.05) |
|---|---|
| LSB-WT | 0.0005 |
| SSB-GU | 0.0000 |
| LSB-GP | 0.0000 |
| 3TE-WT | 0.0005 |
| 3TE-GU | 0.0000 |
| 3TE-GP | 0.0003 |
| 3TQ-WT | 0.0002 |
| 3TQ-GU | 0.0001 |
| 3TQ-GP | 0.0000 |

The experimental results confirmed the importance of mechanical surface treatment. Adhesive bonds for each of the series increased strength from 34 to 1612%. A significant increase in the strength of the adhesive bond occurred in two-component epoxy adhesives labeled 3TE and 3TQ. Cyanoacrylate adhesive LSB indicate relatively high strength without treatment surface (sign WT).

The results of the experiment confirmed a clear positive or negative trend between the place of creation the adhesive bond for two-component epoxy, i.e. NS-I (Indonesia, North Sumatra, region Balige) and

CE-CZ (Prague, CZ, Central Europe). Positively was reflected environments CE-EN for creating of cyanoacrylates bonds (LSB). It was determined increase the adhesive strength from 37 to 59% depending on the surface treatment. This is mainly due to the fact that cyanoacrylate adhesives are during the hardening process sensitive to humidity change. Optimum strength of adhesive bonds by using cyanoacrylate adhesives is achieved at humidity from 40 to 60%. Lower humidity leads to slower hardening. Higher humidity accelerates the hardening process, but simultaneously worsens the final strength of adhesive bond. (LOCTITE, 1998; MÜLLER & VALÁŠEK, 2014B, 2014C).

A principle of the adhesive bond rise is based on a polymeration of put adhesive which is activated by air humidity of the environment and of the adherent. The humidity is neutralized by a stabilizer which is involved in the adhesive and which activates the polymeration process. It comes to a creation of polymerating links in a few "seconds", so the strong bond arises (MÜLLER & VALÁŠEK, 2014B, 2014C).

The adhesive bonds are of adhesive-cohesive failure area. There were no effects to adhesive bond where the adhesive bonds was created Type failure area was dependent on the surface treatment. Especially for adhesive bonds without surface treatment (sign WT) were adhesive failure area.

We concur with the DUCHÁČEK (2006) AND FAIRES (1955) that due to geography and the associated climatic conditions the strength of cyanoacrylate adhesives is changing.

TAMAI AND ARATANIC (1972) observed that within certain limits the roughening of the samples causes decrease of wettability. The simple explanation is that protrusions of elongated ridges create barriers that prevent expansion of drops. Similar conclusions on the aluminium alloy were reached by PEREIRA (2010). He notes that the mechanical properties of unmodified aluminium were higher than for mechanically treated aluminium. These conclusions were not confirmed by experiments.

## CONCLUSIONS

Following conclusions can be deduced from performed experiments:

- The results of experiments confirmed the importance of the mechanical surface treatment AlCu4Mg. The strength adhesive bond with mechanical surface treatment by abrasive cloth of grit P220 increased up to more than 1600%. Two-component epoxy has a higher dependence on mechanical surface treatment AlCu4Mg.
- The results of the experiment confirmed a clear positive or negative trend between the place of creation the adhesive bond for two-component epoxy, i.e. NS-I (Indonesia, North Sumatra, region Balige) and CE-CZ (Prague, CZ, Central Europe). Positively was reflected environments CE-EN for creating of cyanoacrylates bonds (LSB). It was determined increase the adhesive strength up to 59% depending on the surface treatment.
- The adhesive bonds are of adhesive-cohesive failure area. There were no effects to adhesive bond where the adhesive bonds was created Type failure area was dependent on the surface treatment.

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