Agronomy Research **12**(1), 285–290, 2014

The logistics aspects influencing the resultant strength of adhesives at practical application

M. Müller* and P. Valášek

Department of Material Science and Manufacturing Technology, Faculty of Engineering, Czech University of Life Science, Kamýcká 129, 16521 Prague, Czech Republic; *Correspondence: muller@tf.czu.cz

Abstract. Practical application of construction adhesives is required under various climatic conditions and in various environments. The temperature of an environment alone is regarded a limiting factor from the logistics point of view influencing the effectiveness of subsequent application, namely in winter months. The aim of the experimental part is to define the influence of temperature as an essential logistics factor subsequently influencing the resultant strength of the adhesive bond at its application. Further, redress of adhesives properties after extreme temperatures of storing, transit, etc. was investigated. Higher temperatures reached during the logistics flows negatively influence the adhesive bond strength. The temperature also influences change in the failure area.

Key words: adhesive bond creation, bonding technology, climatic conditions, temperature.

INTRODUCTION

Practical application of construction adhesives is required under various climatic conditions and in various environments (Müller 2013; Müller et al., 2013). Each environment has its specific properties, which basically influence the entire strength and reliability of an adhesive bond (Doyle & Pethrick, 2009; Liljedahl at al., 2009; Müller 2013).

Successful use of adhesives in practice is limited by two basic groups of factors. The first group is adhesive properties and the conditions of an adhesive bond creation. Adhesive properties can be influenced, e.g. by unsuitable storing. The second group is the factors exerted by the environment, namely by changes in temperature, humidity, prospective direct contacts with degradation agents. Although both abovementioned groups of influences affect the mechanical properties of adhesive bonds (above all their strength) together, it is important to separately review each particular factor in a form of laboratory experiments, as well as with respect to a particular type of adhesive (Josbi et al., 1997; Müller, 2009; Müller & Herák, 2013; Müller et al., 2013).

Under certain extreme conditions, it is better to use other bonding technologies, e.g. soldering, welding, riveting, etc. In the cases where the bonding method is prescribed, e.g. in a quality manual, it is necessary to follow it.

In various climatic zones, extreme temperatures fluctuations often occur outside in summer and winter months. However, in practice, adhesives can meet much higher or, in contrary, lower temperatures than is recommended by the producer from the logistics flows point of view (sun radiation, sun radiation through glass, transit in a car, storing in an unheated warehouse, etc.). The temperature of the environment alone is regarded as a limiting factor from the logistics point of view influencing the effectiveness of subsequent application, namely in winter months. The storage and working temperature of most adhesives is between 10 and 20°C.

Messler (2004) ascertained the causes of adhesive bond failure by analyzing which unsuitable storage conditions also belong here. It is necessary to consider the climatic conditions in the world at application of adhesives owing to the globalized society (Müller, 2009; Müller, 2013). A considerable fluctuation of the environment temperature is related to it, which can be regarded as extreme for application of adhesives.

The aim of the experimental part is to define the temperature influence as the essential logistics factor influencing subsequently resultant strength of the adhesive bond at its application. Two-component construction adhesives with working temperatures around 20°C were used for the experiments. The interval of tested temperatures ranged from -20 to 100°C. The possibility of applying adhesives the packaging of which was exposed to temperatures from -20 to 100°C was investigated. Further, restoring of the properties of adhesives (the adhesive bond strength) after extreme temperatures of the storage, transit, etc. was investigated. Adhesive bonds were created 24 hours after exposing to specific temperatures. Statistical methods were used for making conclusions.

MATERIALS AND METHODS

The basis of the adhesive bonds laboratory testing was determination of the tensile lap-shear strength of rigid-to-rigid bonded assemblies according to the standard CSN EN 1465. Laboratory tests were performed using standardized test specimens made from constructional plain carbon steel S235J0 according to the standard CSN EN 1465 (dimensions $100 \pm 0.25 \times 25 \pm 0.25 \times 1.6 \pm 0.1$ mm and lapped length of 12.5 ± 0.25 mm).

Ahead of bonding, the surfaces of the bonded specimens were blasted using the Al_2O_3 of F80 grain size (Müller 2011). Using the profilograph Surftest 301, the following values were determined: Ra 1.29 ± 0.07 μm, Rz 6.39 ± 0.33 μm. The surface was chemically cleaned by Acethone P6401 before own adhesive bonding process.

The following list presents identification of the tested adhesives (two-component epoxy adhesives) which are used in text for better, clear arrangement: Bison epoxy metal (BME), Lepox 1200 and hardened P11 (L1200P11), Loctite Nordbak 7256 (LN7256), 3 – TON Epoxy adhesive 30 min (A3T30), 3 – TON Epoxy adhesive 4 min (A3T4). The adhesives are recommended to be applied at the ´room´ temperature, 22 ± 2°C.

Two series on tests were performed. The environment which the adhesives in packaging were exposed to was common for both series. The adhesives (the resin and the hardener) in the packaging were exposed to the surrounding temperatures -20, 22 (the laboratory-comparison standard), 60, and 100°C for the duration of 24 h.

Particular variants of the test are described in the results as xx/yy (e.g. -20/22). ´xx´ means the temperature of the environment which the adhesive was exposed to for 24 hours. ´yy´ (-20, 60, and 100) means the temperature of the orientation of putting the adhesive. The adhesive bonding procedure for the first series was as follows: The adhesive was mixed and applied on prepared bonded surface after removal of the adhesive from the packaging. Own adhesive bonding process was performed at the laboratory temperature (22 ± 2°C). The temperatures of the packaging of all adhesive were measured by means of a contactless infra-thermometer Testo 845 after removing the adhesive from the given environment. Further, temperature was measured during the test that means the temperature of applying the adhesive.

The following adhesive bonding procedure was used for the second series: The adhesive in the packing was removed from an air-conditioner chamber and was left at the laboratory temperature for tempering for 24 h. The subsequent procedure was the same as for the first series. The created adhesive bonds were left to harden for 48 hours under laboratory conditions (22.7 ± 0.5°C). Then, destructive testing on the universal testing machine LabTest 5.50ST followed.

RESULTS AND DISCUSSION

Fig. 1 shows the results of the adhesive bond strength created by means of ANOVA by the lowest squares method. The failure area changed owing to the storage temperature. This change occurred only for some adhesives. Storage temperatures ranging below the freezing point showed up negatively with respect to the possibility of working with the adhesive. Handling the adhesives, i.e. mixing parts A and B exposed to the temperature – 20°C, was possible after 250 ± 120 seconds.

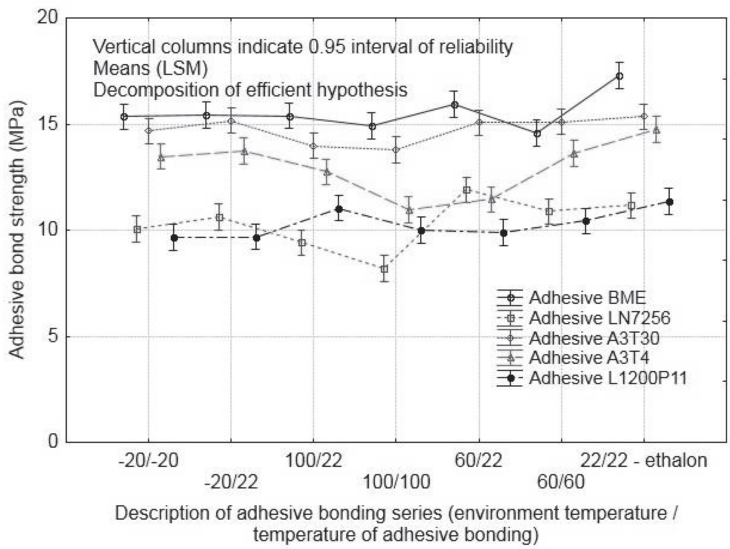

Figure 1. Influence of temperature on adhesive bond strength.

Comparison of series 1 and 2 was performed due to the influence of temperature. T-test was used for the comparison. The state where there is no statistically significant difference between the compared sets from the mean values point of view ($p > 0.05$)

was described as the zero hypothesis H_0. Table 1 shows the conclusions of the performed statistical evaluation.

The statistical evaluation (Table 1) proved that the zero hypothesis was confirmed with all adhesives when comparing the data sets between temperatures -20/-20 and -20/22 ($p > 0.28$). Agreement among particular temperatures in all three cases was only proved with the adhesive A3T30 ($p > 0.11$). Agreement in all cases ($p > 0.09$) was proved among the sets of temperatures data 100/100 and 100/22, except for the adhesives A3T4 ($p = 0.00$) and LN7256 ($p = 0.04$). Arguably, different values were measured at temperatures 100/100 and 22/22 with all tested adhesives ($p < 0.01$). The zero hypothesis was confirmed only with the adhesive L1200P11 ($p > 0.55$) between temperatures 100/22 and 22/22. The dependence always follows the properties of particular adhesives among the sets of temperature data of 60/60, 60/22 and 22/22. No agreement was proved among the compared data sets with the adhesives BME and A3T4. On the contrary, the zero hypothesis was proved in all cases of the comparison with the adhesive A3T30.

Table 1. Statistical comparison of the measured data – T-test; H_0: $p > 0.05$

Adhesive	Comparison	p	Comparison	p	Comparison	p
	-20/-20 : -20/22	0.77	100/100 : 100/22	0.57	60/60 : 60/22	0.00
BME	-20/-20 : 22/22	0.00	100/100 : 22/22	0.01	60/60 : 22/22	0.00
	-20/22 : 22/22	0.00	100/22 : 22/22	0.00	60/22 : 22/22	0.01
	-20/-20 : -20/22	0.37	100/100 : 100/22	0.04	60/60 : 60/22	0.00
LN7256	-20/-20 : 22/22	0.05	100/100 : 22/22	0.00	60/60 : 22/22	0.44
	-20/22 : 22/22	0.40	100/22 : 22/22	0.00	60/22 : 22/22	0.10
	-20/-20 : -20/22	0.28	100/100 : 100/22	0.55	60/60 : 60/22	0.86
A3T30	-20/-20 : 22/22	0.11	100/100 : 22/22	0.00	60/60 : 22/22	0.46
	-20/22 : 22/22	0.69	100/22 : 22/22	0.00	60/22 : 22/22	0.41
	-20/-20 : -20/22	0.54	100/100 : 100/22	0.00	60/60 : 60/22	0.00
A3T4	-20/-20 : 22/22	0.00	100/100 : 22/22	0.00	60/60 : 22/22	0.00
	-20/22 : 22/22	0.00	100/22 : 22/22	0.00	60/22 : 22/22	0.00
	-20/-20 : -20/22	0.98	100/100 : 100/22	0.09	60/60 : 60/22	0.21
L1200P11	-20/-20 : 22/22	0.00	100/100 : 22/22	0.00	60/60 : 22/22	0.00
	-20/22 : 22/22	0.00	100/22 : 22/22	0.55	60/22 : 22/22	0.01

It is optimal to harden the adhesive BME at laboratory temperature. It can be stated that the bonds created at 60/60, 60/22, and -20/22 with the adhesive LN7256 reach statistically comparable values of adhesive bond strength. Higher strength value was reached in the series 60/22. The adhesive A3T30 did not show statistically significant differences in particular test series, except for the series 100/100 and 100/22. The adhesive A3T4 showed statistically significant differences in particular test series, i.e. the adhesive showed lower values of the adhesive bond strength. The adhesive L1200P11 showed values comparable with the laboratory ones in testing at 100/22.

The adhesive A3T30 can be recommended in cases where constant temperature (the laboratory one, 22°C) is not guaranteed due to practical application in the logistics area, i.e. transit, storage, etc. The adhesive LN7256 is suitable for use till the maximum temperature of 60°C. Negative storage values not exceeding the tested – 20°C do not decrease the adhesive bond strength.

Significant differences are visible (Fig. 2) from evaluation of the results of the temperature of put adhesive (series 1). The graph in Fig. 2 was created by means of ANOVA by the lowest square method. The temperature of put adhesive in series 2 did not significantly differ from the laboratory one. The temperature change among particular types of adhesives occurred due to a chemical reaction at mixing the resin and the hardener.

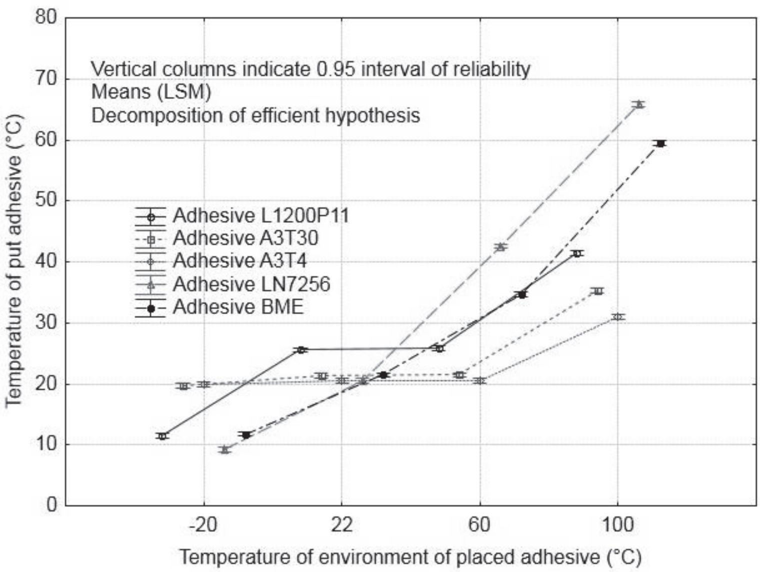

Figure 2. The influence of the environmental temperature of placed adhesive on the total temperature of put adhesive (during the hardening process).

Experimental results confirm the statement of authors about the negative and harmful effects which the environment can have on the adhesive bond (Crocombe 1997; Court et al., 2001; Messler, 2004; Frigione et al., 2006).

CONCLUSIONS

The results of the performed experiments proved the essential influence of storage management (logistic) in the area of adhesive bonding technology. The results suggest a necessity to keep the technologic discipline in the area of the storage temperature guaranteed by a producer.

The adhesive A3T30 can be recommended in cases where constant temperature (the laboratory one, 22°C) is not guaranteed due to practical application in the logistics area, i.e. transit, storage, etc. The adhesive LN7256 is suitable for using till the maximum temperature of 60°C. Negative storage values not exceeding the tested – 20°C do not decrease the utility properties.

The following points were ascertained by comparing the ascertained values with the comparison standard 22/22:

- There was a considerable fall in the adhesive bond strength values with all adhesives in series 1. This was at the temperatures – 20°C and 100°C (variants -20/- 20 and 100/100). The average fall of the adhesive bond strength was 9.78 % for the variant – 20/- 20 and 17.66% for the variant 100/100.
- A lower fall of the strength occurred at the temperatures – 20 and 100°C in series 2, i.e. at the adhesives which were left for tempering at laboratory temperature for 24 h after exposal to increased/decreased temperature. The average increase of the adhesive bond strength in series 2 compared to series 1 was as follows: 2.5 % for the variant – 20/20 and 7.5% for the variant 100/22.
- At the temperature of 60°C, the adhesive bond strength fell as well as increased. The difference between series 1 and 2 was also not unambiguous.

ACKNOWLEDGEMENT. Supported by the Internal grant agency of the Faculty of Engineering, the Czech University of Life Sciences in Prague.

REFERENCES

Court, R.S., Sutcliffe, M.P.F. & Tavakoli, S.M. 2001. Ageing of adhesively bonded joints – fracture and failure analysis using video imaging techniques. *International Journal of Adhesion & Adhesive* **21**(6), 455–463.

Crocombe, A.D. 1997. Durability modelling concepts and tools for the cohesive environmental degradation of bonded structures. *International Journal of Adhesion & Adhesives* **17**(3), 229–238.

Doyle, G. & Pethrick, R.A. 2009. Environmental effects on the ageing of epoxy adhesive joints. *International Journal of Adhesion & Adhesives* **29**(1), 77–90.

Frigione, M., Aiello, M.A. & Naddeo, C. 2006. Water effects on the bond strength of concrete/concrete adhesive joints. *Construction and Building Materials* **20**(10), 957–970.

Josbi, S.B. Gray, T.F., Banks, W.M., Hayward, D., Gilmore, R., Yates, L.W. & Pethrick, R.A. 1997. Environmental ageing of adhesively-bonded joints II. Mechanical studies. *Journal of adhesion* **62**(1–4), 317–335.

Liljedahl, C.D.M., Crocombe, A.D., Wahab, M.A & Ashcroft, I.A. 2007. Modelling the environmental degradation of adhesively bonded aluminium and composite joints using a CZM approach. *International Journal of Adhesion & Adhesives* **27**(6), 505–518.

Messler, R. W. 2004. *Joining of materials and structures from pragmatic process to enabling technology*. Burlington: Elsevier, 790 pp.

Müller, M., Chotěborský, R. & Hrabě, P. 2009. Degradation processes influencing bonded joints. *Research in Agricultural Engineering* **55**(1), 29–34.

Müller, M. 2011. Influence of surface integrity on bonding process. *Research in Agricultural Engineering* **57**(4), 153–162.

Müller, M. & Valášek, P. 2013. Degradation limits of bonding technology depending on destinations Europe, Indonesia. *Tehnicki Vjesnik-Technical Gazette* **20**(4), 571–575.

Müller, M. 2013. Research of liquid contaminants influence on adhesive bond strength applied in agricultural machine construction. *Agronomy Research*. **11**(1), 147–154.

Müller, M. & Herák, D. 2013. Application possibilities of adhesive bonds – Europe, Indonesia. Scientia Agriculturae Bohemica. **44**(3), 167–171.