Bearing capacity and corrosion weight losses of the bonded metal joints in the conditions of Indonesia, North Sumatra province

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ABSTRACT: The article is focused on the analysis of the bonded metal joints capacity and corrosion weight losses in the conditions of equatorial Indonesia – North Sumatra province. For the purpose of the given article, the province was divided into three main climatic zones: Medan, Balige, Pagarbatu, where the dependence was observed of the bonded joints capacity on the duration of the weather exposure. The joints life and their further usability were predicted based on the analyses of the measured values.

Keywords: capacity; joints; durability; usability; tropical area; corrosion

The development of bonded joints is obvious in all possible industrial branches at the present time. Bonding is becoming a more important joint technique with classical and perspective materials. The development of novel adhesives brings new opportunities for the bonding technologies applications. In many cases, bonding is the only suitable technology, fulfilling the demands for the final joint quality. The bonded joint is a complicated and combined system whose quality is influenced by many factors, such as the reactions during the materials and glues preparation, the joint assembly and glue setting or the joint use.

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. The climatic influence and different geographical conditions, however, appear to decrease the joint and materials capacity. Susceptibility to corrosion and the durability of parts or machines may differ by up to 50% (Faires 1955).

The bonded joints reach maximal strength after a certain period, dependent on the setting speed, thus on the solidification reactions of the glue. The way and process of the glue solidification are different for each kind of the technique, material or glue used. The glue solidification process is influenced in most cases by the ambient temperature.

The glue solidification process of the joint may be simply described as a glue change from the liquid to the solid state with the concurrent adhesive and cohesive bonds formations. The development of such a process varies in the use of different glues and is influenced by various factors. These may be divided into technological factors and those influenced by the bonded joint surroundings. The first group of the factors mentioned above is represented by the way of the glue preparation, the amount of glue used for bonding, and the connected materials effects. The

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second group of the influencing factors is represented by the temperature, moisture, and other physical properties. However, all the factors mentioned above act together and mutually influence one another. Their importance and impacts depend mostly on the kind of glue used and the kind of solidification reaction (Marghitu 2001; Ševčík 2005).

The knowledge of technological properties influencing the bonded joint is important for a successful use of the glues chosen. During the selection of the glue application, it is also very important to accent the surrounding conditions and long term degrading processes appearing in the joint. The degrading processes significantly influence the mechanical properties during the bonded joint life. The strength limits of the bonded joint reached at the beginning of its life span may decrease with time (Oberk *et al.* 2000).

It is necessary to focus the bonded joints testing and valuating not only on the possible changes of the strength properties but also on the boundary section between the connected material and glue. The connected material is also affected by weathering due to the more or less degrading surrounding. Destruction of the bonded materials may appear in extreme cases and when corrosion is present. Such degraded surfaces of the bonded materials will be sooner or later functionless. So called "sub-corrosion" of the glue layer appears and due to adhesive forces, representing a part of the solid bond. The degree of the corrosive action depends upon the kind and structure of the bonded material and, last but not least, on the corrosive surroundings.

Corrosion is an undesirable and permanent change of the material surface, caused by chemical and electrochemical effects of the surroundings. It is defined as the degradation of the material and represents a complex of physical and chemical processes the final consequence of which is total material destruction.

Anti-corrosion protection optimisation is based on the knowledge of the corrosive process and of the mechanism of the anti-corrosion system function. The framework program of the optimal system designing is obvious by the specification of the function requirements and setting of the surrounding aggressiveness. Economical issues are also necessary to dealt with. By the valuation of these enter data is it then possible to set and design a protective system.

METHODS

The knowledge obtained during previous experiments was applied in the preparation of bonded joints exposed to the degrading processes. The bonded joints were prepared at optimal values of the surface modification, as well as of the thickness of the bonded layer. The parameters mentioned significantly influence the strength quality of the bonded joints.

During the experiment, two component glue Bison epoxy metal was tested, which had provided satisfactory and relatively high values of strength in previous experiments. The experimental testing was done in agreement with the Czech standard of ČSN EN 1465 (1997, Determining of the duct shear strength of the solid adherents at the flashing joints). The object of the testing was the determination of the strength of the simple flashing bonded joint stressed by the tensile force acting in parallel with the surface of conglutination and the tested sample main axis until the deformation of the sample took place.

The adjustment of the bonded surface of the material to the chemical composition given in Table 1 was achieved by blasting with Al_2O_3. The size of the blasting particles was F24 and the thickness of the bonded layer was 0.1 mm. In the case of resins, the recommended thickness of the bonded layer is between 0.1 and 0.2 mm. A mixture of the resin and the hardener was prepared in the specified ratio (1:1). The mixture of glue was applied on the sample surface at the period prescribed, distant wires were applied and the other part of the bonded joint was placed, and the parts were fixed together. Both parts of the bonded joints were fixed with lead of the weight of 720 g. The tested samples of sizes 100 × 25 × 1.5 mm were bonded together, the recommended length of the overlapped parts being 12.5 mm.

In order to found out the effects of the degrading processes on the bonded joints, a basic set was prepared of samples solidified at the laboratory

Table 1. Chemical composition of the bonded material (weight %)

Element	C	Mn	Cr	Ni	Al	Cu	Nb	Ti	Fe
Steel 11 373	0.047	0.240	0.076	0.017	0.065	0.039	0.007	0.016	99.5

Figure 1. The main experimental locations shown on the map of the North Sumatra (Syarbaini 2004)

temperature of 23 ± 2°C in observance of the climatic conditions of the Czech Republic. The samples were then transported to Indonesia by air.

The measurements were done in Indonesia, North Sumatra region, which is characterised by tropical weather throughout the year, with minimal changes. Virtually, the fall or winter seasons do not exist. The year is divided there into the "wet" and "dry" periods. The dry season takes place from June to September; the rainfalls are brought by the Eastern monsoons from December to March. In the transition period there are beautiful sunny days alternating with days with occasional rains. Even in the middle of the "wet" period, the temperatures often reach 21°C–33°C. Exceptional are the mountainous locations in high altitudes where the temperatures are frequently lower. The most frequent rain falls are usually recorded from December to January. The average air humidity value fluctuates from 70–100% (Stone *et al.* 1994).

Although Indonesia belongs to the equatorial countries, the climatic conditions are not the same throughout the country. The altitudes range from the sea level regions to the mountainous regions at 3 000 m a.s.l. Different elevation levels exhibit various rain falls, temperatures and humidity.

According to Figure 1, the Indonesian province of North Sumatra can be divided into three basic climatic parts:

Medan – atypically tropical area on the shore of the Chinese Sea, with the elevation nearly 0 m a.s.l., the average daily temperature about 31°C, humid-

Table 2. The measured values of the bonded joints strength capacity (N)

Time (month)	Location – area		
	Medan	Balige	Pagarbatu
0	6 800	6 800	6 800
2	4 920	6 765	5 888
4	4 506	6 610	5 580
6	3 826	6 436	4 634
8	3 360	6 190	3 840

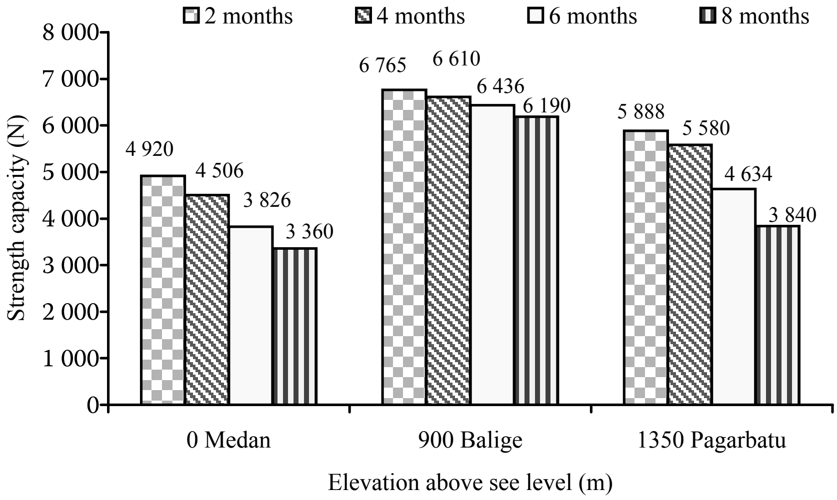

Figure 2. Dependence of the bonded joints strength capacity on the elevation and exposure time

ity around 90%. The precipitations are 2 200 mm per year (Vaisutis *et al.* 2007).

Balige – this location is found in the area located at 900 m a.s.l., close to the Lake Toba, with the daily average temperatures around 25°C, humidity app. 80%. The precipitations are 1 800 mm per year (Syarbaini 2004).

Pagarbatu – this location founds itself on a mountain plateau at 1 350 m a.s.l., with the daily average temperatures around 25°C, humidity app. 90%. The precipitations are 2 400 mm per year (Situmorang 2007).

Each set of the tested samples were exposed to weathering by the surrounding environment for the selected periods (2, 4, 6, 8 months) in each location. Then, the change of strength was observed in each tested samples series. The samples were not loaded with any burden except their own weights, theywere merely exposed to the surroundings. In the so called "zero" time, the samples strength was determined under the laboratory conditions in the Czech Republic. The samples tested in Indonesia were collected in each location at the selected time periods (mentioned above) and then transported to the Czech Republic by air, where their shear stress capacities were determined. In total 160 samples were used, each collection containing 10 samples which means 4 × 10 samples per one collection at one time in each of the localities mentioned.

The bonded joints or glued materials were not modified or treated with any anti-corrosive operation. Where the corrosion layer occurred on the bonded materials (steel 11 373, equal to S235JO), by ČSN EN 10020 (2001), the corrosive loss was observed and tested. The corrosive loss was measured by laboratory weighing using Chirana P3/200 prescale, measuring with the accuracy of 0.1 g. The same scale was used to determine the gross weight, and subsequently high-precision scales were used. The obtained weight values were tested using 0.00001 g

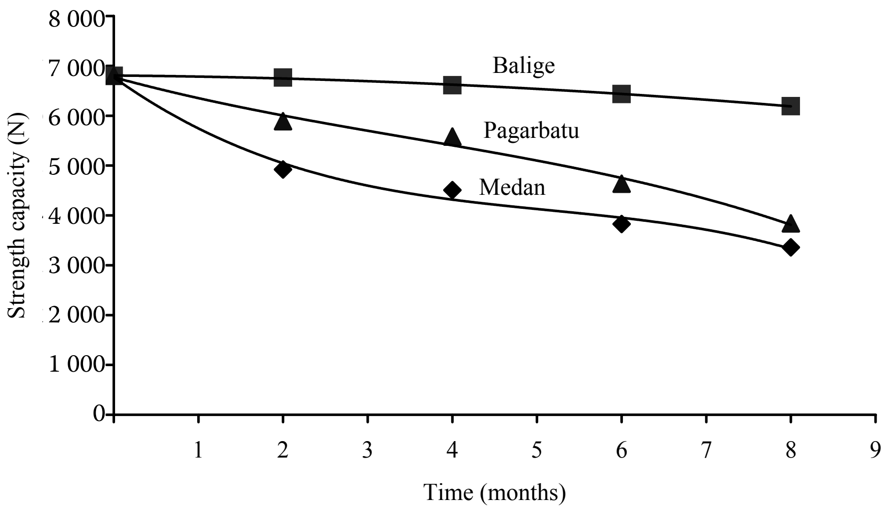

Figure 3. Dependence of the bonded joint on the exposure time

Table 3. Presumed strength capacity of the bonded joints

Area	Time (month)					
	2		5		10	
	strength capacity					
	(N)	(%)	(N)	(%)	(N)	(%)
Balige	6 756	99	6 532	96	5 940	87
Pagarbatu	6 004	88	5 101	75	2 370	35
Medan	5 064	74	4 127	61	1 818	27

accurate scales. Due to the exact weight set, a calibrated scale WA 35, type PRL T A 14, was used. In order to reduce inaccuracy, the measurements were repeated and then evaluated.

MEASUREMENTS

The measured values were processed into Table 2. If these values are pictured in the column chart given in Figure 2, clearly visible dependence is obtained of the bonded joint strength capacity on the exposure time and elevation.

The measured values can be expressed by the point chart (Figure 3) as the dependence of strength on the exposure time and observed location – area.

If these dependences measured are smooth by the polynomial function, mathematical equations, describing dependences of the joint capacity on the exposure time, are obtained:

Balige area

$$C_B = -7.8869 \times t^2 - 41.321 \times t + 6\,806.9 \quad (1)$$

where:

C_B – capacity in Balige area (N)

t – exposure time (month)

$$R_B^2 = 0.9978 \quad (2)$$

Pagarbatu area

$$C_p = -4.7188 \times t^3 + 49.455 \times t^2 - 463.64 \times t + 6\,770.9 \quad (3)$$

where:

C_P – capacity in Pagarbatu area (N)

t – exposure time (month)

$$R_P^2 = 0.9887 \quad (4)$$

Medan area

$$C_M = -13.042 \times t^3 + 202.25 \times t^2 - 1\,213{,}3 \times t + 6\,768.4 \quad (5)$$

where:

C_M – capacity in Medan area (N)

t – exposure time of (month)

$$R_M^2 = 0.9901 \quad (6)$$

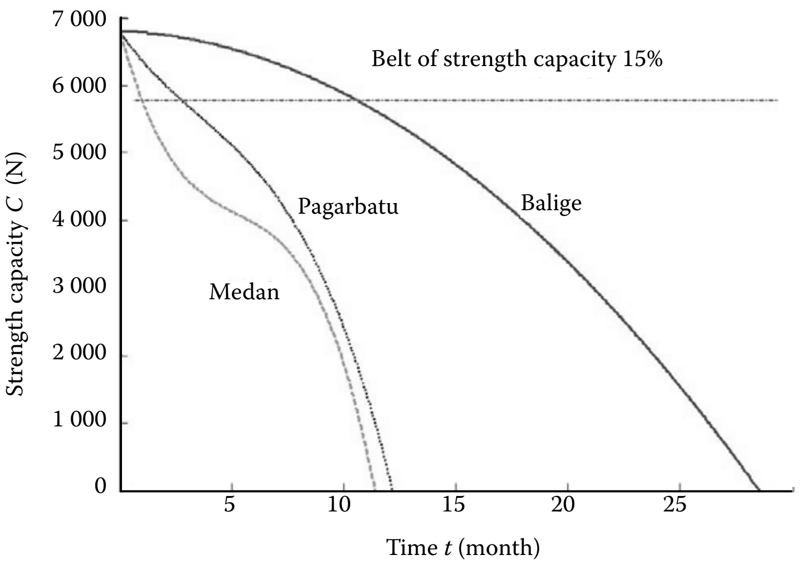

Figure 4. Presumed strength capacity of the bonded joints

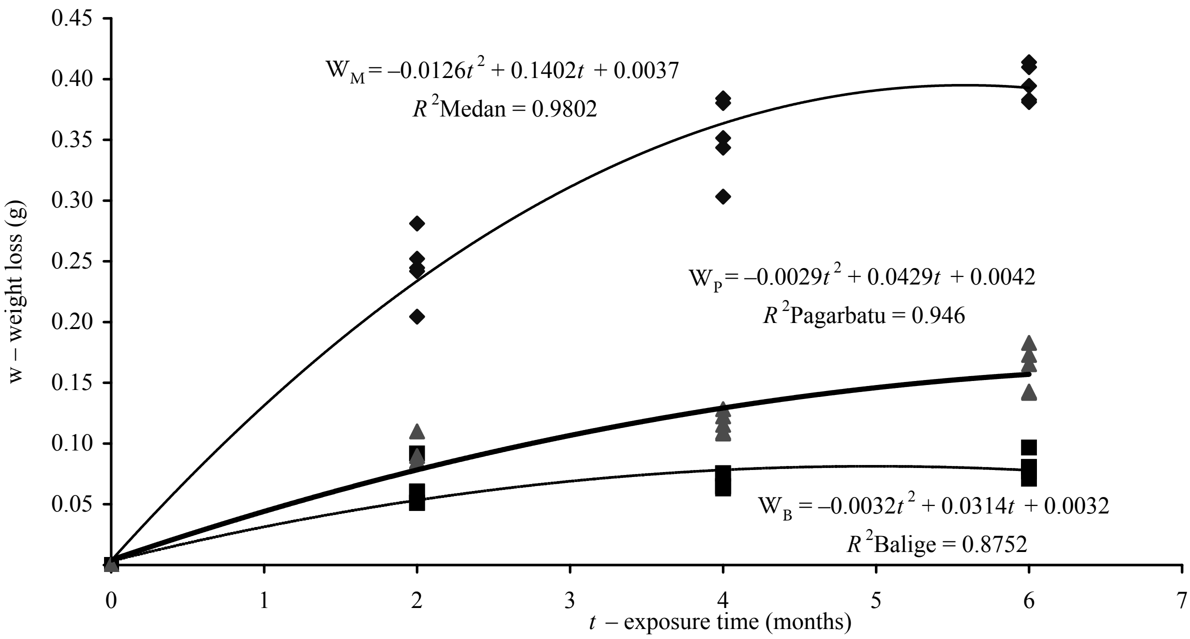

Figure 5. Corrosion weight losses of the tested samples during different climatic conditions

DISCUSSION

The decreasing of the strength capacity is obvious from the measured values, leading to the decrease of the joints life in the dependence on the exposure time. By means of Eqs. (1), (2), (3) of the dependences pictured above is it possible to predict the quality of each joint on a longer time line. The calculated values of the strength capacities dependent on the time exposure are presented in Table 3.

Proportional values are also pictured of the strength capacity decreasing toward "zero" time conditions. The measurements obviously show that the samples in Balige area are characterised by a low value of the strength capacity decrease. Using Eq. (1), the presumed time can be set a rapid deterioration of the bonded joint appears. Such time is actually the life span of the bonded joint and is 29 months for Balige area. In the area of Pagarbatu, a rapid loss of the strength capacity appeared already after two months of exposure time. If the life span of the bonded joint is set for Pagarbatu area, using Eq. (3) reveals that the life span of joints there is merely 12 months. The bonded joint in Medan area showed the most rapid loss of the strength capacity, 25% decrease of the strength capacity having appeared within the first two months. From Eq.(5), the life span of such a joint is only 11 months in this location.

During the real constructional practice, it is also important to set a belt of the strength capacity. The constructor may calculate 15% variance in the tabled values during the bonded joint proposing and calculating.

If the Eqs of the supposed strength capacity of each joints Eqs (1), (2), (3), together with the belt of applicability (Figure 4). In the presented case, by the application of 15% from the so called zero capacity the real time is found of the bonded joints usability in the selected areas. From the graphical expression is it obvious that the possibility of the real utilisation of the bonded joint is merely 0.93 months in Medan, 2.64 months in Pagarbatu, and 10.5 months in Balige.

The degradation of the bonded material (steel S235J0) revealed itself by the weight loss in the material and shape (surface) changes. The surfaces of the measured materials as well as the surface of the bonded area (length of the bonds) were taken into account while the corrosive losses were tested. The surfaces of the tested samples were about 10 750 mm^2 and lengths of the bonded joints (glued surface) about 12.5 ± 0.25 mm.

The results of the measurements and the dependences involved are presented in Figure 5. The true behaviour of the corrosion process of the bonded materials was, however, considerably influenced by the climatic conditions to which the tested samples were exposed. On the steel surfaces of the bonded joints placed in Medan, a continuous layer of corrosion was observed. On the surfaces of the samples placed in Balige and Pagarbatu, the layer of corrosion was not continuous, but places with quite different levels of corrosion appeared.

The highest material weight losses appeared in the case of samples placed in Medan area. The closeness of approach, R^2 was 0.8752 up to 0.9802, for the curves. This indicates that the value of R^2 is very high.

CONCLUSION

Based on the experimental setting of metal bonded joints in three climatic locations in Indonesia – North Sumatra province, the following may be stated:

The use of the joints bonded and solidified in the Czech Republic (the area of moderate belt) with the application of standard glues of European production is quite inadvisable in all three described locations of Indonesia, North Sumatra region. The joints were tested in the absence of stress. In the experiments using loaded samples or samples dynamically strained, worse results of the life span or stress capacity are to be expected.

The appearance of corrosion was observed on the surface of the tested steel samples. The samples in Medan area were covered by the overall layer of corrosion. Corrosion had the same progress on the whole surface. Corrosion also appeared on the samples placed in Balige and Pagarbatu, however, its appearance was not regular as spots shoving strong or light corrosion were observed.

The work on the experiment is going on. At the present time, samples are tested which were bonded and solidified – hardened in Indonesia and then placed in the areas mentioned. The degree of corrosion dependent on the exposure time in each climatic area is also part of the research.

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Abstrakt

Herák D., Műller M., Karanský J., Dajbych O., Simanjuntak S. (2009): **Únosnost a korozivzdornost lepených kovových spojů v podmínkách Indonésie – provincie Severní Sumatra**. Res. Agr. Eng., **55**. 94–100.

Článek je zaměřen na analýzu únosnosti a velikosti koroze lepených kovových spojů v podmínkách rovníkové Indonésie – provincie Severní Sumatra. Během prováděného dlouhodobého výzkumu byla tato provincie rozdělena do tří hlavních klimatických pásem: Medan, Balige, Pagarbatu, ve kterých byla pozorována závislost únosnosti lepeného spoje na době expozice. Z analýzy naměřených hodnot byly poté stanoveny předpokládané životnosti lepených kovových spojů.

Klíčová slova: únosnost; spoj; životnost; použitelnost; tropická oblast; koroze

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