

BEARING CAPACITY OF RESISTANCE SPOT WELDING UNDER CONDITIONS OF EUROPE, INDONESIA

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Abstract

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A common attribute of production companies is a requirement for a bond creation. A resistance spot welding is a prospective method of bonding. An effect determination of environmental influences on mechanical properties of resistance spot welded bonds is necessary owing to export activities of particular companies. The operating conditions and degradation processes influence were examined in Central Europe, southeast Indonesia and laboratory during 2, 4 and 6 months. From the results the simulation was worked out serving for the prediction of the welded bond bearing capacity for longer time interval. The simulation was verified by the parametric testing during 80 months (Central Europe). The experimental determination of the climatic and geographic different environment influence on the bearing capacity of the resistance spot welded bonds was the aim of the laboratory testing. Considering the globalized society and the export possibilities the knowledge of the experimental study will be used for further testing.

Keywords: bonding, degradation, globalization, prediction, testing

INTRODUCTION

A common attribute of production companies is a requirement for a bond creation. Also unremitting innovations and searching for new prospective technologies which facilitate the production process are connected with it (Abe *et al.*, 2009; Mucha, 2011).

A choice of a suitable bonding method is one of basic steps which are needed for ensuring a competitiveness (Müller and Valášek, 2013; Müller, 2014). It is possible to characterize three basic ways of bonding – mechanical, heat and chemical one. When applying a particular bonding technology a knowledge of technologic principles which influence qualitative features of the final bond is important (Müller, 2014). When deciding about the bond type advantages and limits of applied technologies comparing with other ways of bonding have to be taken into regard (Müller, 2014).

The production of bonds by the resistance spot welding technology belongs among simple that means technologically less demanding.

The resistance spot welding belongs among a resistance welding that means a metallurgical bond is created.

Spot welding is the most common joining process for automotive body constructions due to its production convenience and cost effectiveness (Khandoker and Takla, 2013).

A bonding method “Clinching” can be classified among significant other methods. This method uses a shaping for the bond creation. It serves for bonding of materials using one or multi-degree production process. This principle can be characterized by a transfer of the material combined with a local cut or a plastic deformation and subsequent cold pressing (Abe *et al.*, 2009).

Another significant group of bonding of different materials is an adhesive bonding technology. Its applications have become more significant recently. The adhesive bonding technology usage considerably increases and it is used in a number of industrial branches. Its significance as the bonding technology is increasing owing to a number

of advantages comparing with other bonding method (Müller and Herák, 2013). However, it is influenced by many factors which have a considerable significance from the bond strength and service life point of view.

Also combined bonds occur in a technical practice e. g. the welding and the adhesive bonding. Al Samhan and Darwish dealt with a prediction of the strength of welded/adhesive bonded bonds (Al-Samhan and Darwish, 2003). Their work presents results synergically combining properties of the adhesive layer and the welded bond.

Welded bonds form an integral part of steel constructions. Welded and riveted bonds are undetachable bonds, which are however subjects of corrosion processes (Černý and Filípek, 2011). The internal energy increases during the welding fusion especially in the places of the welded bond, which become initiating spot of corrosion degradation (Votava, 2013).

Resistance spot welding is a very effective method to join two or more metal sheets together with heat produced by welding current and it is widely used in automotive industry (Zhang *et al.*, 2014). The stiffness, strength and integrity of the vehicle constructions depend in part on the quality of the resistance spot welds.

The corrosion degradation of technical materials is an irreversible process, which results in a gradual destruction of the whole machine part. Even though the welding belongs to the most widely used production technologies of fixed bonds, it has to be stated that a partial degradation of the base material occurs. This statement was proved by metallographic scratch patterns. It is mainly about the changes in the structure in the heat affected zone (Černý *et al.*, 2007). Weld undercuts and teeth at the edges of welded bond are also evident. Later, such places may initiate cracks in the material. As during the welding process a lot of energy is brought to the material, it can be supposed that the corrosion pressure on welded metal will be increased.

The experimental determination of the climatic and geographic different environment (Europe, Indonesia) influence on the bearing capacity of the resistance spot welded bonds was the aim of the laboratory testing. Considering the globalized society and the export possibilities the knowledge of the experimental study will be used for further testing.

MATERIALS AND METHODS

Test samples made from the constructional steel S235J0 were used for the experimental research. Sizes of the test sample which was welded were 1×15×105 mm (placed in Europe and Indonesia) and 1×45×105 mm (made according to standard ČSN EN ISO 14273).

The number of the test specimens for each series was 12 pieces. Eight pieces each series were determined for own destructive testing. Other

four pieces were determined for measuring of the microhardness.

Geographic and Climatic Specification of Testing Environments

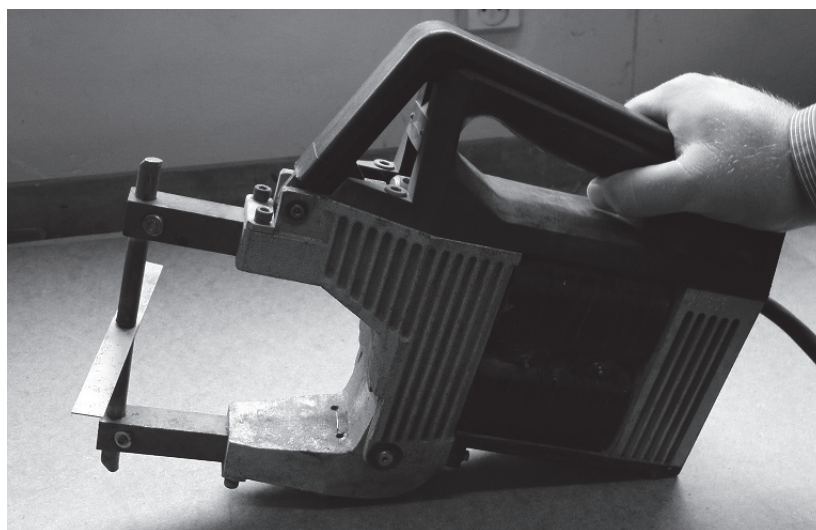
Central Europe is situated in the mild climatic zone of the northern hemisphere. It is the transition zone. Warm summer with rainfalls alternates with winter with lasting snow cover. Europe is especially characteristic by industrial production, which is exported all around the world. But at the present time this influence goes missing.

Indonesia 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. The average air humidity ranges from 70 to 100%. In consideration of the volcanic activity and Indonesia climate conditions the soil is very fertile. Regarding the region advanced level and number of inhabitants (the fourth most populous state) agriculture is put on the dominant position (Müller *et al.*, 2013; Müller and Valášek, 2012). At the present orientation it is primarily possible to assume import of agricultural technology, which is nowadays solved by import above all from the Asian region, i.e. from China. In countries of the Third World the import and application of new prospective technologies have a row of specifics, which are given by the level of education, political situation and environmental specifics. The use of modern technologies including service is very limited. It is necessary to pay attention to low failure rate, possibility of simply renovation and absence of complicated mechanisms (Müller *et al.*, 2013; Müller, 2013). The resistance spot welded technology meets the above mentioned requirements.

The test samples were placed in Indonesia in three regions: **Region Medan** – altitude 0 m, average daytime temperature 31 °C, relative humidity 90%. **Region Balige** – altitude 900 m, average daytime temperature 25 °C, relative humidity 80%. **Region Pagarbatu** – altitude 1350 m, average daytime temperature 25 °C, relative humidity 90% (Müller *et al.*, 2013).

The test sample determined for the long-term exposition under the conditions of Europe and Indonesia was of smaller width than it is stated in the standard. The width was smaller of cca 66%. Exported bonds were also without foundation sheets of metal in the place of clamping into a jaw of the testing machine. The foundation sheets of metal were adhesive bonded before own testing process. A reason for the change of the sizes was the financial costs for the transport into three different areas of Indonesia. Comparing tests were performed for harmonizing with the results gained at the standard test samples. The standard allows this possibility.

A surface of test samples was treated by grit blasting by a corundum of a fraction size F80. A mechanical treatment of the surface belongs among significant factors (Holešovský *et al.*, 2012;



1: Welding of steel test samples

Novák, 2012; Novák, 2011). Many authors deal with a research of the surface treatments.

A resistance electrode holder BV2 521 was used for the resistance spot welding, a maximum welding current is 6.4 kA, a maximum force among electrodes is 2 kN. It is declared a nugget of a size 3 to 3.5 mm. Soft resistance spot welding mode (that means low currents and long welding time intervals) was used at the samples production.

A principle of the bond rise is following: The mechanical treatment of the surface. Setting of parameters on a regulator that means the welding time 0.2 s for materials of the thickness 1 + 1 mm. Putting welded materials (overlapped) among welding electrodes (Fig. 1). Pressing of welding electrodes – a transit of the electric current for the stated time.

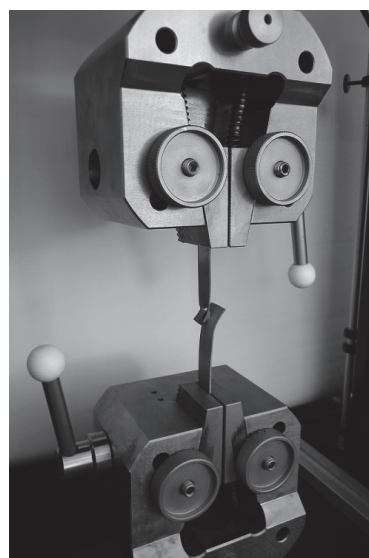
Created overlapped bonds (1×15×105 mm) were placed in laboratory and outside (Europe, Indonesia).

Within Europe, it was Prague in the Czech Republic. In Indonesia, there were two regions Medan and Balige which are situated in a north part of Sumatra. The region Balige is situated at largest volcano lake Danau Toba. The region Pagarbatu is situated in island Java.

The operating conditions and degradation processes influence were examined in Central Europe in Prague, Indonesia and laboratory (comparing etalon) during 2, 4 and 6 months.

After passing the time exposition to which the welded overlapped bonds were exposed these bonds were closed into vacuum packing. In case of the samples in Indonesia these samples were brought back to Europe after passing last time interval. Consequently, a destructive testing was performed.

A destructive testing that means a tensile shear strength test was performed on a universal testing machine LABTest 5.50ST (a sensing unit AST type KAF 50 kN, an evaluating software Test&Motion).

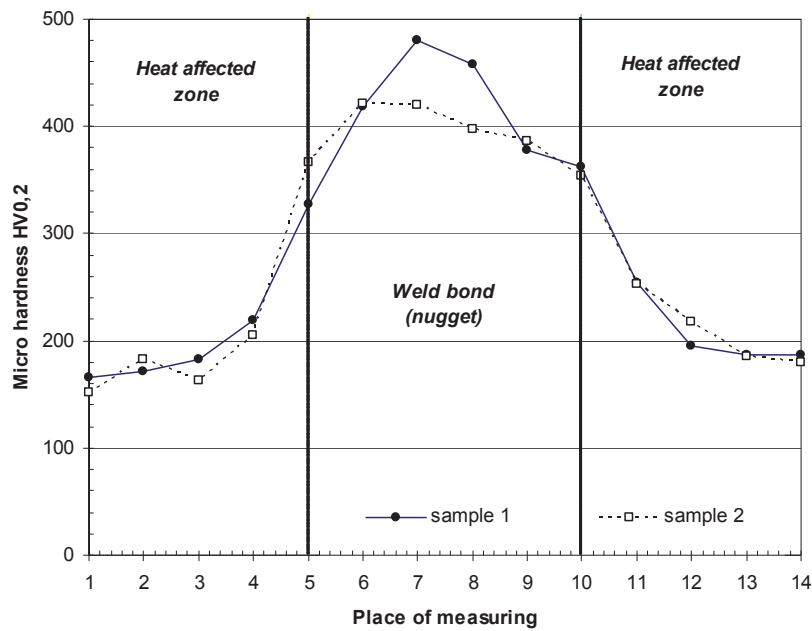


2: Destructive testing of test samples

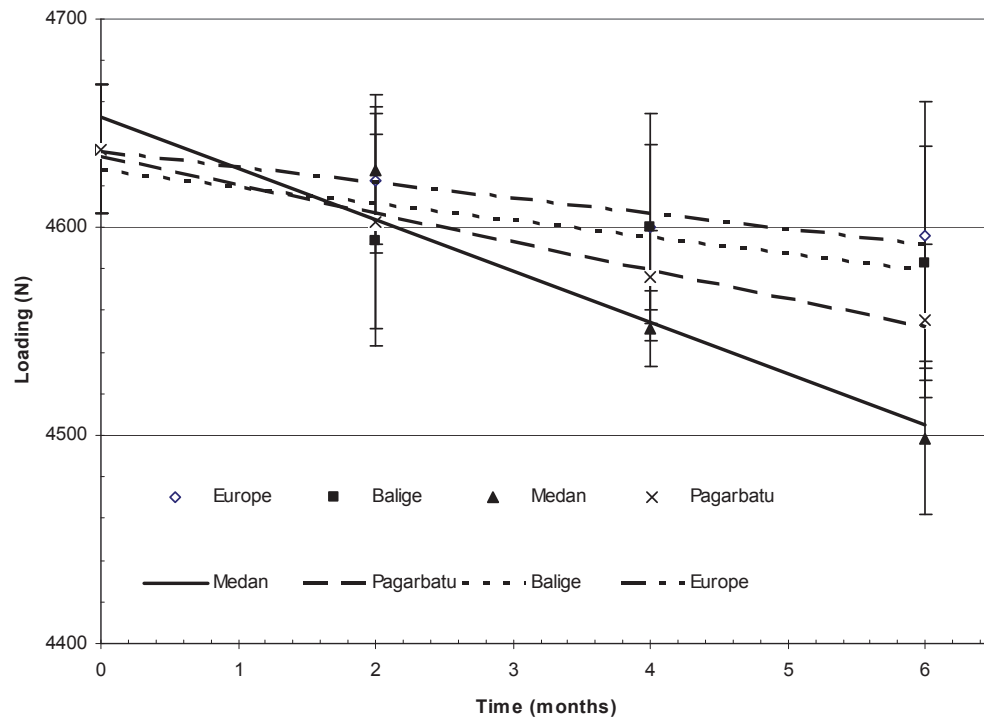
A speed of the deformation corresponded to 6 mm·min⁻¹. The destructive testing is visible in Fig. 2. An evaluating criterium was a set loading force (N) and a type of the weld failure. A size of the nugget was evaluated on the basis of a picture analysis. A deformation angle of the spot welded material was measured after the destruction by means of a mechanical protractor. A microhardness HV0.2 was measured in a cut of the destroyed bond.

RESULTS

Soft resistance spot welding mode is distinguished for higher heat affecting of welded materials. This fact was certified at measuring of the microhardness HV 0.2. Results of the microhardness measuring are visible from Fig. 3. The average value of the nugget was 3.66 ± 0.12 mm. The heat affected zone around the nugget was measured as 1.04 ± 0.23 mm.



3: Results of microhardness measuring



4: Environment and exposure time influences on loading of resistance spot welded bonds

Comparing tests focused on different overlapped width (15 and 45mm) confirmed a decreasing of the bearing capacity of bonds created by the resistance spot welding of 22.3%. The standard states the decreasing of the bearing capacity of 10% for 33.3% of decreasing of the sample width. At the experiments the sample width was decreased of 66.6% which corresponds to decreasing of the bearing capacity of cca 20%.

A graphical presentation of results of the resistance spot welded bonds bearing capacity is presented in Fig. 4. For the correct evaluation it is also important to determine the determination index R^2 . It is the problem of the correlation analysis. The values of the determination index can be from 0 to 1. The functions presented in Fig. 4 are determined by equations in Tab. I.

I: Equations of linear functions

Destination	Functional equations	R ²
Europe	$y = -7.3125x + 4636$	0.94
Medan	$y = -24.625x + 4652.6$	0.93
Balige	$y = -7.9375x + 4627.3$	0.74
Pagarbatu	$y = -13.688x + 4633.9$	0.99

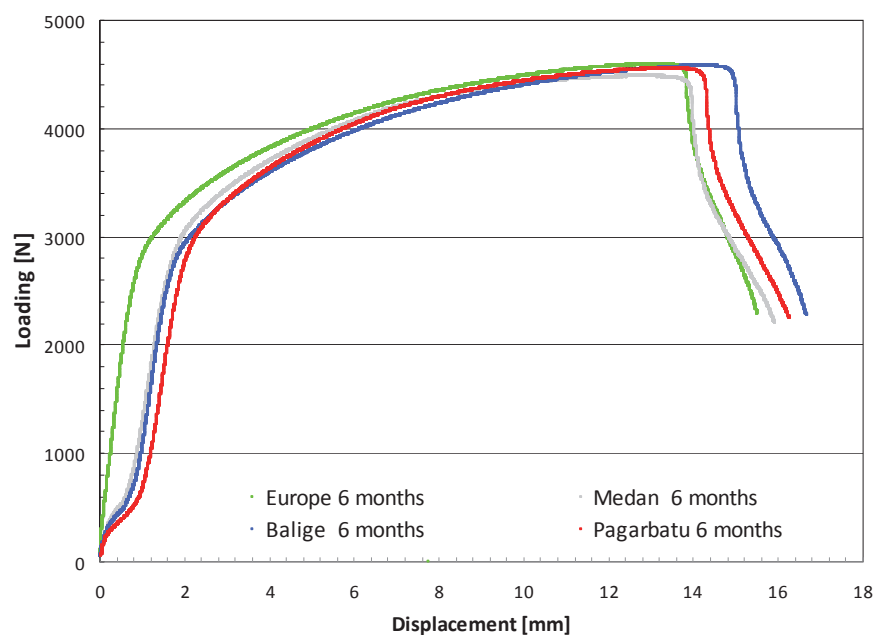
The results of the bearing capacity present an arithmetical mean of data ascertained in the reliability interval α 0.05 (Tab. II). Tukey's HSD test was used for the statistical comparison of the mean value. It is possible to say on the basis of the results of Tukey's HSD test that they are statistically non-homogeneous groups (Tab. II).

It followed from the results that the tested sets are distinguished for three different groups from the homogeneity point of view.

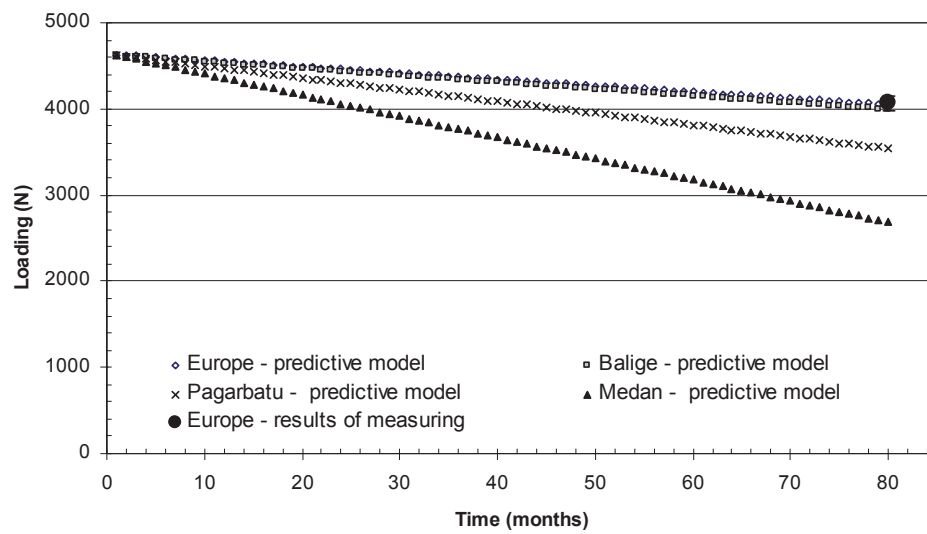
Degradation environments were mutually compared among each other using F-test ANOVA always after passing particular time of the degradation from the influence of various degradation environments on the bearing capacity of the spot welded bond point of view. The zero hypothesis H_0 presents the state when there is no statistically significant difference ($p > 0.05$) among tested sets of data from their mean values point of view. The environments Europe ($p = 0.2828$) and Balige ($p = 0.2011$) certified the hypothesis H_0 , so there is no difference among particular tested time intervals (0 to 6 months) on the reliability level 0.05

II: Statistical comparison of mean values – Tukey's HSD test

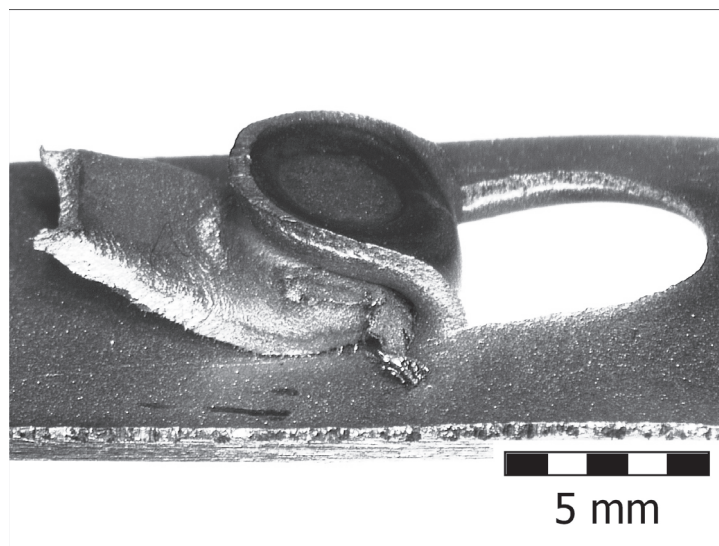
Time (months)	Destination	Bearing capacity – Arithmetical mean (N)	Agreement		
			1	2	3
6	Medan	4498.75	*		
4	Medan	4551.25	*	*	
6	Pagarbatu	4555.00	*	*	
4	Pagarbatu	4576.25		*	*
6	Balige	4582.50		*	*
2	Balige	4593.75		*	*
6	Europe	4596.25		*	*
4	Europe	4600.00		*	*
4	Balige	4600.00		*	*
2	Pagarbatu	4602.50		*	*
2	Europe	4622.50		*	*
2	Medan	4627.50		*	*
0	Etalon	4637.50			*



5: Tensile diagram



6: Correlation between real and predictive influences of environment and exposure time on loading of resistance spot welded bonds



7: Destruction of resistance spot welded bond

between Europe and Balige. The environments Medan ($p = 0.0001$) and Pagarbatu ($p = 0.0018$) did not certify the hypothesis H_0 , so there is the difference among particular tested time intervals (0 to 6 months) on the reliability level 0.05. Results of F-test ANOVA were confirmed by Tukey's HSD test.

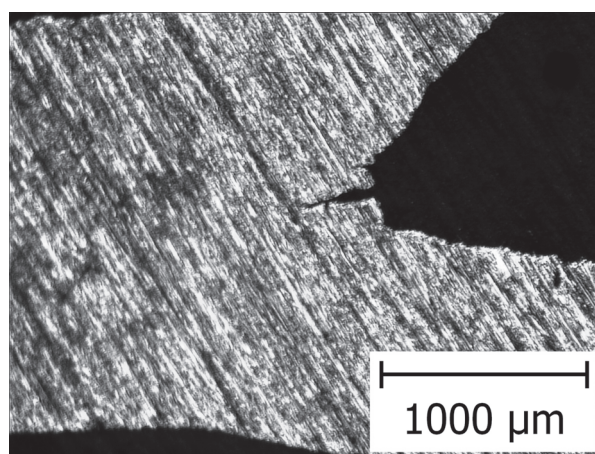
Dependence curves of the cross – bar motion line and the loading in particular degradation environments are visible from tensile diagrams (Fig. 5).

The basic measurement in the interval '0' to 6 months was used to the predictive model creation. By the substitution in the functional equations (Tab. I) the predictive dependence of the 80 months interval was created. For the comparison of the presupposed and real values the reference tests of the same exposure time in the European environment were performed. In Indonesia

the reference tests were not performed because of operational reasons. The correlation results of the real and predictive values are presented in Fig. 6.

The difference between predictive and measured data in the interval 80 months was 0.35% in Europe. Results of the one-choice t-test confirmed that the testing criterium did not exceed the critical value $t_{0.95}$. It follows from above stated that there is no difference between tested values (that means measured and predictive data).

The bond failure occurred always in the boundary of the nugget and bonded materials (Fig. 7). It is obvious from the results of investigating of the cut of the resistance spot welded bond that cracks occurred in the own welded bond (after the bond destruction, Fig. 8). A corrosion of the bonded material is the significant factor of the welded bond strength.



8: Cut through destroyed resistance spot welded bond

DISCUSSION AND CONCLUSION

This fact of the strength differences minimization with respect to the climatic and geographic world order is the significant aspect for producers and importers of machines and devices containing adhesive bonds (Müller and Valášek, 2012).

Taking into consideration the importance of various climatic conditions is evident from experiments made by Müller and Herak (2013) who judged the environment effects on the strength of the adhesive bonds exposed during 8 months (graded after 2 months) to the Indonesian tropical climate conditions, concretely of three regions, which differed in altitude, daytime temperature and relative humidity.

The common criterion of the average weld nugget diameter is equal to a fourth part of the material thickness (where t is the material thickness in mm), which pullout failure is guaranteed in the tensile shear test (Zhang *et al.*, 2014). According to a calculation of Honggiang *et al.* the maximum nugget diameter should be 4 mm.

The average value of the nugget was 3.66 ± 0.12 mm. The test results confirm the influence of different climatic and geographic conditions on the resistance spot welding bond.

It is possible to say from the results of Tukey's HSD test that they are statistically non-homogeneous groups. There is difference between Europe and particular regions of Indonesia (Medan and Pagarbatu) from the statistical comparison point of view. Lower values of the relative humidity are in the region Balige. The region Balige is comparable with the conditions in Europe from the statistical analysis point of view.

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