WELD-BONDING A STATE OF ART REVIEW

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ABSTRACT

This paper presents a review of weld-bonding process. The aim of this paper is to increase the understanding of the weld-bonding as joining methods for structural purposes. It is a method of joining metals which involves Resistance Spot Welding used in combination with a structural adhesive. The increasing demand of lightweight materials and heavy need of lightweight structures with better joint strength have justified the wide use of weld-bonding techniques. Recent work relating to finite element analysis and practical experimentations of weld bonded joints is reviewed in this paper, in terms of static loading analysis, fatigue loading analysis and dynamic characteristics of the weld bonded joints. The brief understanding of this weld-bonding process will help to research for further work on it. The present study consist of all necessary details of introduction, need of weld-bonding, influencing parameters, advantages, and literature review of past work done on weld-bonding.

Keywords: adhesive bonding, aluminium, bonded joint, weld-bonding, spot welding.

I. INTRODUCTION

Joining of materials is an important feature of many material processing and production industries. Currently light weight materials such as aluminium alloy widely used in industries to reduce the weight of the assembly. Weld-bonding is the good alternative method of joining aluminium alloy. This joining technique has the advantage of being good fatigue resistant and lightweight joints. This method depends on adhesive bonding, a joining process that has been around for the last 5000 years and resistance spot welding.

Weld-bonding is an alternative Joining technique generally used for joining of sheet metals. Weld-bonding was first developed in Soviet Union for the AN-24 planes. Weld-bonding is the combination of two different types of joining processes e.g. resistance welding and adhesive bonding. This is a hybrid joining process in which the structural adhesive is applied on the overlapping area of faying surfaces of the specimen and subsequently spot-welded before the curing of the adhesive take place. Thus combination of these two joining techniques makes weld-bonding as a hybrid joining process.

The bond can be formed by two different techniques:

1- Applying the adhesive first and then the spot-weld.

2- Spot-welding first and applying the adhesive afterwards.

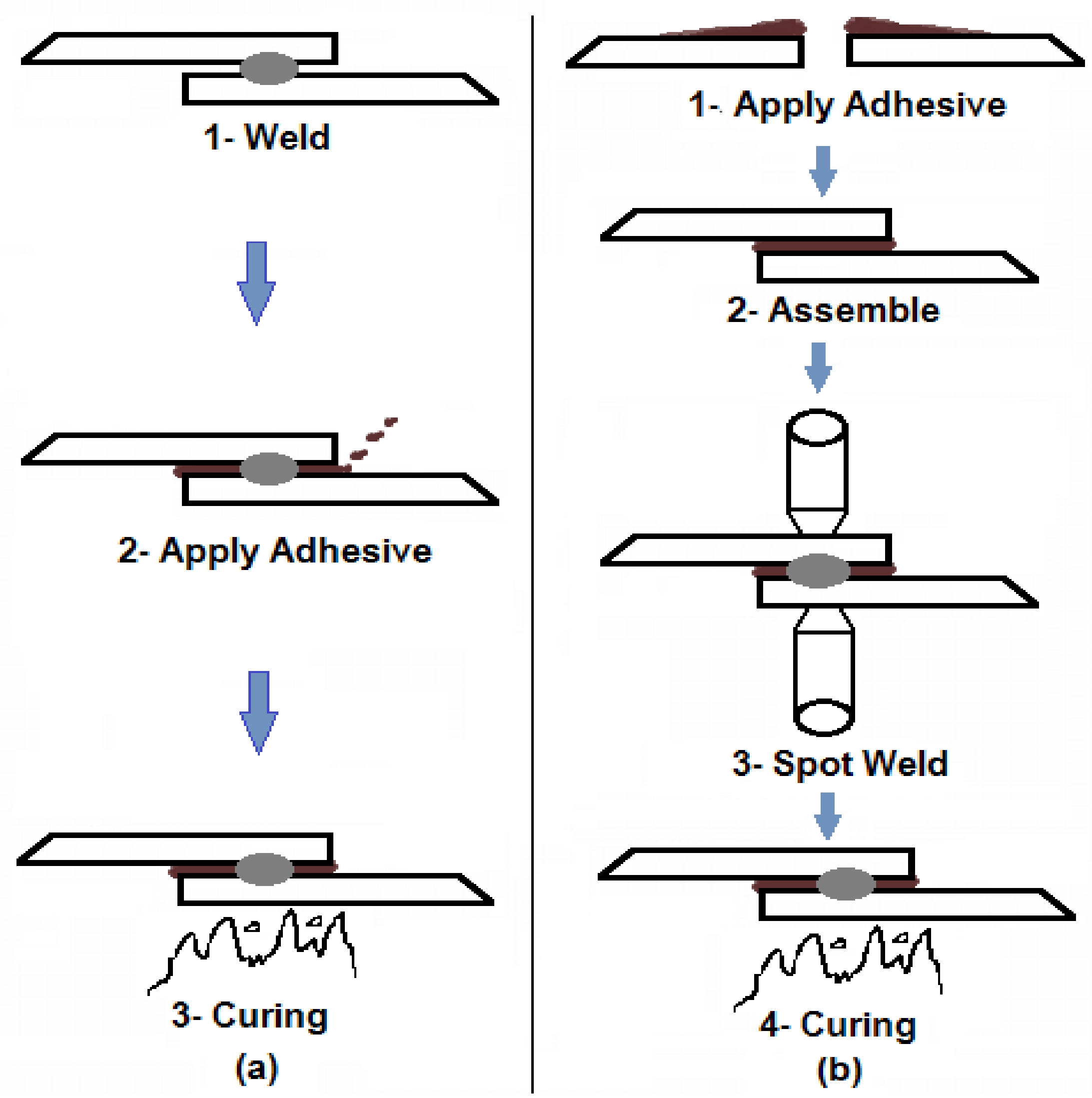

Fig. 1: Weld-bonding Techniques (a) Flow-in (b) Weld-Through.

These both Techniques are shown in above (Figure 1). The first technique is known as **Flow-in** technique. This method is based on capillary forces to distribute the adhesive. The second technique is known as **Weld-Through** technique. This technique has proven to give less thermal stresses, although it makes the spot-welding more difficult whereas flow-in technique is easier to implement, better microstructure of weld nugget and cheaper to use. Weld-bonding generally used for lap type of joints. Generally weld-bonding has been used for spot-welded constructions to increase their fatigue and static strength, but also used in such constructions where adhesive bonding acts as a primary method, and one wants to eliminate the requirement of fixtures for the curing process.

Weld-bonding increases the fatigue life of the structure that made by spot welding, by the addition of adhesive in the joint. Since adhesive increased the area of joining by large overlap area so that this more area distributed the load on the joints more evenly and also due to this larger load bearing area the possibility for crack propagation reduces in the spot-weld since propagation of crack must start through the adhesive layer as well. Weld bonded joint have fatigue strength between spot-welded joint and a pure adhesive joint.

II. NEED OF WELD-BONDING:

The increasing demand of lighter, fast, cheap and stronger joints require new joining methods. In this manner resistant spot welding is a good option for fast, cheap and lighter joints but strength of joints may or may not be high because of such type of welding which depends on the **weldability rating** of the working material. Weldability rating of any metal depends on three factors namely (a) resistivity, (b) melting temperature, and (c) thermal conductivity.

The weldability rating of any metal given by following formula:

$$W = (R/FKt) \times 100$$

Where W = Weldability rating

R = resistivity

F = melting temperature of the metal in degree Celsius.

Kt = relative thermal conductivity with copper equal to 1.00

So according to above formula, metals those having properties like low value of thermal conductivity, high resistance and relatively low value of melting temperature are very easy to weld. Metals having low value of resistivity but a high value of thermal conductivity are difficult to weld. Since aluminium possess low value of resistivity and a high value of thermal conductivity so resistance spot welding is difficult for aluminium and does not produce a sound weld like steel or titanium.

Table 1. Weldability rating for metals [1]

Metal	Aluminium	Magnesium	Inconel	Nickel	Monel	Low-carbon steel	Low-alloy steel	Stainless steel	Titanium
Weldability Rating	0.75-2+	1.80	2+	2.15	2+	10+	10+	35+	50+

The weldability rating for aluminium lies between 0.75-2 that does not show good weldability of aluminium. Thus adhesive bonding comes as additional joining method with resistance spot welding to increase the strength of aluminium joint, this additional method makes it a hybrid joining technique named weld-bonding. So this weld-bonding is a good option to get higher static strength of joint with several other weld-bonding advantages over the resistance spot welding [1].

III. INFLUENCING PARAMETERS FOR WELD-BONDING:

The joint strength of weld-bonding process gets affected by various parameters. These parameters are shown in figure 1 below. Since weld-bonding is a combination of adhesive and spot welding thus this joining process mainly influences by adhesive parameters as well as resistance spot welding parameters but also by some other parameters like type of adherend material, test method, and environmental conditions ext.

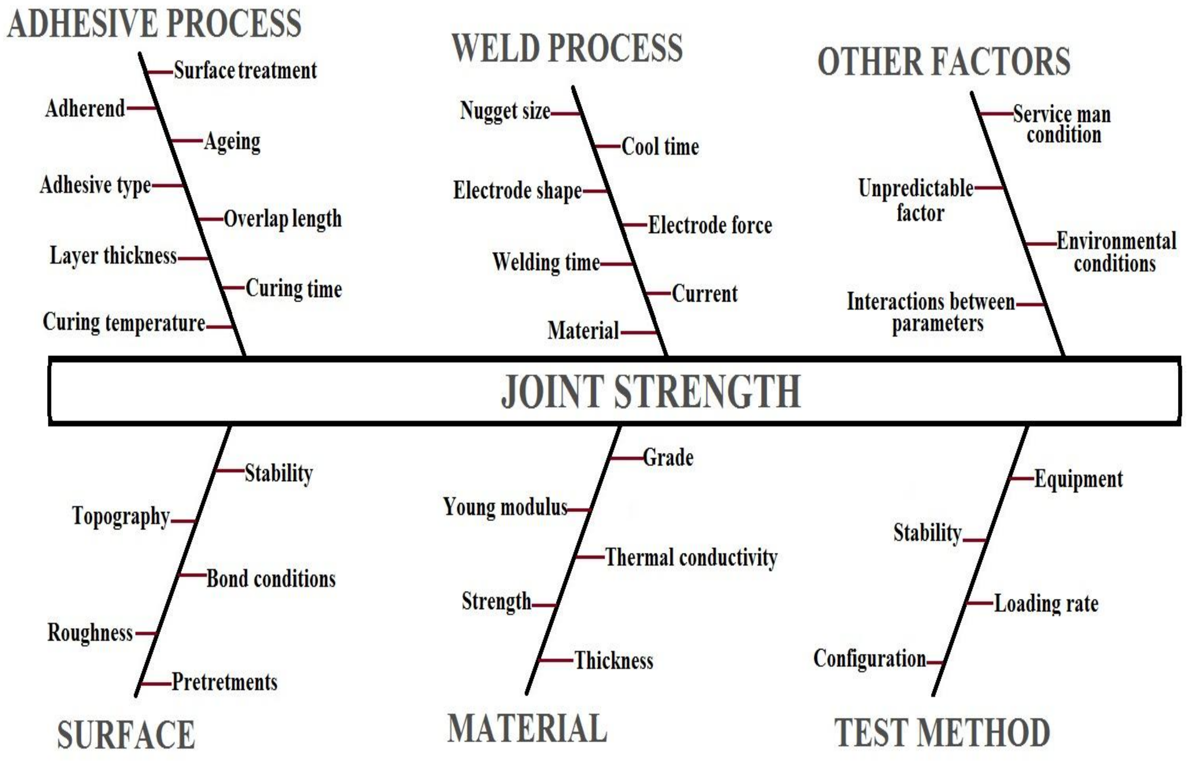

Fig. 2: Parameters affecting weld-bonded joint.

IV. LITERATURE REVIEW

K.C. Wu is the one of the oldest researchers in the field of weld-bonding. He studied resistance spot welding with different high contact resistance surfaces. He took 1.6mm thick aluminium alloy sheets and produced a high contact resistance between them by providing different surface treatments. The reason for creating such a high contact resistance was only to make this resistance spot welding equivalent to weld-bonding on the basis of resistance only, further he has performed spot welding on these high contact resistance surfaces with respect to different welding parameters and established a suitable welding schedule to produce an expulsion free good quality welds. Because of its high contact resistance, expulsion comes out as a severe problem in weld-bonding type joints so K.C. Wu resolved this problem in this paper [2] [3]. **P.C. Wang et al.** investigated the fatigue behavior and microscopic examinations of Aluminum joint under weld bonded joint. The microscopic examination gave the information regarding two failure modes of the weld bonded aluminium joints that are “adherend-tearing” and “nugget-through”. The experiments were carried out on Aluminium 5754-H40 with bis-pheonol an epoxy adhesive. The experimental results showed that adhesive bonded aluminium had a slightly higher fatigue resistance when compared with weld-bonded aluminium. The decrement in fatigue strength of weld bonded occurs due to the presence of spot welded joint [4].

Baohua Chang et al. investigated the stress distribution in adhesive bonded, spot-welded and weld-bonded joints by using finite element method for analysis. They also studied fatigue properties of weld bonded joints and compared this with spot welded joints. They took 08Al as a base metal and SHA-2858 Epoxy as an adhesive. Results from numerical analysis show that the stress concentration occurred at boundary of spot weld zone. Since stresses in the area of adhesive joint distributes more evenly, thus no stress concentration found in weld-bonded joints so presence of adhesive strengthened the weld bonded joint. Fatigue test outcome showed higher fatigue life of the weld bonded joints than that of spot weld and a little less than that of adhesive bonded and concluded that existence of the adhesive in the spot weld increases the fatigue life of the joints [5]. **B. H. chang et al.** explained the effect of two important parameters of adhesives i.e. elastic modulus and adhesive thickness on the stress distribution in weld-bonding. They used 3D finite element method with 08Al Steel as a substance. After all the theoretical analysis, they showed that (1) the decreased value of the elastic modulus leads to increment in stresses around spot weld nugget in weld-bonding. (2) A thick layer leads to low value of shear stress and a high value of normal stress at the lap edge in weld-bonding joints. So based on these results they concluded that a thin adhesive layer with high value of elastic modulus leads to minimum stress concentration in weld bonded joints [6] [7]. **Jun Hee song et al.** investigated the effect of various parameters such as overlap length, added pressure, overlap width and surface treatment on the shear strength of the adhesive bonding. They do all the experiments on 1.2mm thick steel sheets. They used Ultimate tensile strength machine to determine the tensile shear strength for all the joints under different parameters [8].

Further studies on stresses in weld bonded joints done by **A. Al. Samhan et al..** They showed variation of all the stresses along the overlap area and along the mid layer of the spot welded, adhesive bonded and weld bonded joints individually and then they compared all these three types of joints on the basis of different stresses found in that joints. All work done on FEM of Calsef finite element program. Results showed that (1) stresses are concentrated at both ends of the overlap area alone the applied load but for spot welded joints, stresses are concentrated at the outer boundary of the welded nugget. And (2) five to six times more major principal stresses found in spot welded joints than that of weld bonded joints. A. Al Samhan et al. further studied two different types of adhesive layers with square and spew fillet ends and their effect on the strength of weld bonded joints. They concluded that adhesive layer with spew fillet is better to strengthen the weld bonded joints [9] [10]. Further **S.M. Darwish** alone worked on aluminium sheets to explain the dynamic response of the weld bonded joints and compare this response with spot welded joints. He took 4 input variables i.e. force, current, time and sheet thickness with two levels for each variable and plotted their dynamic response on graphs for both weld bonded and spot welded joints. On the basis of results he concluded that spot welded joints possessed low value of damping capacity when compared to weld-bonding joints, and results also showed an independent behavior of natural frequency for both joining techniques. In his further research **S.M. Darwish** studied weld-bonding with dissimilar thickness joints and dissimilar materials. He used finite element modeling technique for this work. For dissimilar thickness he took 4 different thickness specimens i.e. 1mm, 1.5mm, 2mm and 2.5mm in finite element model and dissimilar material, he took 3 different materials i.e. steel, aluminium and brass, then he showed the variation of all the stresses for dissimilar thickness and for dissimilar materials individually for both weld bonded and spot welded joints. After comparison of stresses for both joining techniques, he concluded that higher stress concentration occurred at thin member of dissimilar thickness joints and also at weakest member of dissimilar material joints in spot welded joints but the presence of adhesive layer in weld bonded joints cut down all the stress concentration and balance the stresses in both dissimilar thicknesses joints and dissimilar material joints [11] [12] [13]. Further **S.M.H. Darwish et al** evaluated the performance of the weld-bonding techniques namely, flow in and weld through techniques. Both techniques were evaluated on the basis of metallurgical examination and microhardness of weld section. The metallurgical examination done by photomicrographs, that were conducted at 300* (300 times magnification) for microstructure and 37.5* for welding nugget. The measurements for microhardness were taken along both minor and major axes of the weld nugget. He also tried to show the effect of fillers materials (that increases electrical conductivity of adhesive materials) on weld bonded joints. The results showed that, it is easier to implement flow in weld bond techniques because of having better hardness and microstructure unlike weld through technique, also weld through technique is much expensive thus it is beneficial to use flow in technique rather than weld through technique. They further investigated the thermal stress developed in weld-bonded joints. He carried out the experiment to show the effect of weld-bonding technique, electrode pressure, types of adhesive materials and bond line thickness on the development of thermal stresses. The results that came out from finite elements analysis showed that the thermal stresses were concentrated around the periphery of the weld nugget. The maximum thermal stresses associated with flow in technique are much higher when compared with weld through technique. Result also showed that for thinner bond line there is higher peak stresses present in the weld bonded joint and for obtaining the sound weld bonded joint, low young's modulus adhesive is useful [14] [15].

I.O. Santos et al. studied weld-bonding on stainless steel in this paper they investigate the effect of working time of three commercial adhesives on strength of weld bonded joints. They also investigated the effect of different surface conditions on the joint strength. On the basis of all the investigation, they found degradation occurred in the strength of weld-bonding if weld-bonding done after max working time of that particular adhesive thus they recommended that weld time should be less than that of maximum working time of all the adhesives. They also showed that a surface with residual oil does not provide a strong bond unless that surface undergoes clean and degreased with some acids like acetones [16]. Up to this none of the researchers worked to develop an efficient model for simulation of weld-bonding but **Young Xia et al.** done this work in 2009, he developed a new technique for efficient modeling to produce a good quality of weld bonded joints for steel substance in vehicle structure. They studied all the possible factors that affected the static and dynamic experiments. Based on these static and dynamics experimental findings and based deep study on present (current) modeling approaches in FEM program. They combined the mesh-independent spot weld model with constrained spot weld model for modeling the weld bonded joint for steel substance. This combined model was very useful to simulate the failure and deformation of weld bonded joints in vehicle structure in highly efficient manner [17] [18].

Further **Y.S. Zhang et al.** Studied weld bonded and spot welded joints for steel substance and compared the weld nugget of both joining techniques based on their microstructure and mechanical properties. All study done experimentally on DP780 steel specimens with spherical electrode of Cr-Zr-Cu. A general epoxy adhesive is used with a curing time of 30 minutes on 180°C. They did tensile shear force, energy absorption and microhardness test for weld nugget under both joining technique. After all experimentation it was found that at smaller welding current weld bonded nugget have higher tensile shear force(TSF) and energy absorption capacity but at relatively larger welding current, the weld-bonding nugget have slightly lower TSF when compared with spot welded nugget , Because of a heavy expulsion occurred in weld bonded nugget and destroyed it. They were also found on the basis of microstructure characterization and hardness test that weld bonded nugget possessed of finer martensite, with respect to smaller hardness value and bigger nugget size at lower current [19].

Further **Min You et al.** studied on preformed angle of weld bonded specimens and investigated the effect of this angle on stress distribution either close to interface or along the mid bond line of the adhesive in the joint. They took aluminum alloy as working substance and phenolic resin as an adhesive for modeling in ANSYS FEM software. They analysed the longitudinal, peel and shear stresses in weld bonded joints under varying preformed angle i.e. 0°, 3°, 6°, 9°, and 12° based on all the analysis of stress variation, they concluded that 6° degree preformed angle is suitable to improve load capacity of weld bonded joint [20]. Further in their next paper **Min You et al.** studied on fillet angles of adhesive and their effect on stresses in weld bonded joints, they analysed all the stresses at different fillet angles i.e. 30°, 45°, 60° and 90°. Since previous study showed that maximum stresses were found at the both ends of the adhesive joints thus it is beneficial to have a fillet at the ends of the joint to reduce the stress concentration. Based on all the analysis they concluded that 30°-40° fillet angle is suitable to improve load capacity of weld bonded joint [21].

V. ADVANTAGE OF WELD-BONDING OVER RESISTANCE SPOT WELDING

These are the following advantages of weld-bonding over resistance spot welding.

1. High static strength.
2. Improved fatigue strength.
3. Improved corrosion resistance.
4. Superior energy absorption capacity for impact loading.
5. No need of sealing operation (adhesive makes the joint sealproof).
6. Increased damping capacity.

VI. APPLICATIONS OF WELD-BONDING

It is evident from literature survey of weld-bonding that it has several benefits than individual one. The current use of weld-bonding in engineering applications is at aerospace and automobile industry. The excellent fatigue property and better static strength of joint makes the light-weight structure possible for assembly in automobile sector and thus this light weight structure increases the strength to weight ratio.

VII. CONCLUSIONS AND FUTURE SCOPE

Weld-bonding is a good method for joining the two sheets/plates and provides better strength of joint than that of individual spot weld joints or adhesive joint. The literature survey shows about the comparative study of adhesive bond and resistance spot weld with weld-bonding and tells about the variation of the stresses across the weld-bonding joint. This joining method consist of good fatigue properties, peel strength, and high tensile shear strength. Based on previous work there are plenty of field for future work on weld-bonding like influence of nano particles on joint strength, weld-bonding for thicker aluminium and their comparative studies with spot welding and creep behavior of weld-bonding with spot welding etc.

REFERENCES

[1] Howard B. Cary, Scott Helzer, Modern Welding Technology (Pearson Education, US, 2005).

[2] K.C.WU, (1975), "Resistance spot welding of high contact-resistance surfaces for weld-bonding", Welding Journal, pp. 436S-439S.

[3] K.C.WU, (1977), "The mechanism of expulsion in weld-bonding of anodized aluminium", Welding Journal, Vol. 56, Number 8, pp. 238S-244S.

[4] P.C.Wang, S.K.Chisholm, G.Banas, F.V.Lawrence, Jr., (1995), "The roll of failure mode, resistance spot weld and adhesive on the fatigue behavior of weld bonded aluminium", Welding Journal, Vol. 74, Number 2, pp. 41S-47S.

[5] Baohua Chang, Yaowu Shi, Shijie Dong, (1999), "Comparative studies on stresses in weld-bonded. Spot welded and adhesive-bonded joints", Journal of Materials Processing Technology, Number 87, pp. 230-236.

[6] B.H.Chang, Y.W. Shi, S.J. Dong, (1999), "A Study on the role of adhesives in Weld-Bonded joints", Welding Research Supplement, pp. 275S-279S.

[7] Baohua Chang Yaowu Shi, Liangqing Lu, (2001), "Studies on the stress distribution and fatigue behaviour of weld bonded lap shear joints", Journal of Materials Processing Technology, Number 108, pp. 307-313.

[8] Jun Hee Song and Jae Kyoo Lim (2001), "Bonding Strength in Structural Adhesive Bonded Joint", Metals and Materials International, Vol. 7, No. 5, pp. 467-470.

[9] S.M.Darwish, A. Al-Samhan, (2003), "Strength prediction of weld-bonded joints", International Journal of Adhesion & Adhesives, Number 23, pp. 23-28.

[10] A. Al-Samhan, S.M.H. Darwish, (2002), "Finite element modeling of weld-bonded joints", Journal of Materials Processing Technology 142, pp. 587–598.

[11] S.M.Darwish, (2003), "Characteristics of weld-bonded commercial aluminium sheets (BS. 1050)", Journal of Materials Processing Technology, Number 23, pp. 169-176.

[12] S.M. Darwish,(2003) "Weld-bonding strengthens and balances the stresses in spot-welded dissimilar thickness joints" journal of material processing technology 134, pp. 352-362.

[13] S.M. Darwish, (2003) "Analysis of weld-bonded dissimilar materials", International Journal of Adhesion & Adhesives 24, pp. 347–354.

[14] S.M.Darwish, A.Al-Samhan, (2004), "Thermal stresses developed in weld-bonded joints", Journal of materials processing technology, Number 153-154, pp. 971-977.

[15] S.M.H. Darwish, A.Ghanya, (2000), "Critical assessment of weld-bonded technologies", Journal of Material Processing Technology, Number 105, pp. 221-229.

[16] I.O.Santos, W.Zhang, V,M.Goncalves, N.Bay, P.A.F.Martins, (2004), "Weld-bonding of stainless steel", International Journal of Machine Tools and Manufacture, Number 44, pp. 1431-1439.

[17] YongXia, QingZhou, P.C.Wang, N.L.Johnson, X.Q.Gayden, J.D.Fickes, (2009), "Developmentofhigh-efficiencymodelingtechniqueforweld-bondedsteel joints invehiclestructures—PartI:Staticexperimentsandsimulations", International Journal of Adhesion & Adhesives 29 , pp. 414–426.

[18] YongXia, QingZhou, P.C.Wang, N.L.Johnson, X.Q.Gayden, J.D.Fickes, (2009), "Development of a high-efficiency modeling technique for weld-bonded steel joints in vehicle structures, Part II: Dynamic experiments and simulations", International Journal of Adhesion & Adhesives 29 , pp. 427–433.

[19] Y.S.Zhang, H.T.Sun, G.L.Chen, X.M.Lai, (2009), "Comparison of mechanical properties and microstructure of weld nugget between weld-bonded and spot-welded dual-phase steel", Journal of Engineering Manufacture, Number 1475, pp. 1341-1350.

[20] Min You, Jialing Yan, Dingfeng Zhu, Jianli Li, Jingrong Hu, (2010), "Effect of Preformed Angle on Stress Distributed in Weld-Bonded Aluminum Single Lap Joints" International Conrference on CET, Vol.5, pp. 582-586.

[21] Min You, Dingfeng Zhu, Jialing Yan, Cunjun Chen, Chunzhi Mei, (2011), "Effect of fillet angle on stress in weld-bonded aluminum joints" IEEE Publications.