CHARACTERIZATION OF ELETRIC RESISTANCE SPOTWELD MAIN DEFECTS BY ULTRASONIC INSPECTIONS AND THEIR METALLOGRAPHIC INTERPRETATIONS.

Danilo Stocco
DaimlerChrysler do Brasil Ltda - Centro Tecnológico – Av. Alfred Jurzykowski, 562 – 09680.900 São Bernardo do Campo – SP - danilo.stocco@daimlerchrysler.com

Gilmar Ferreira Batalha
Lab. Engenharia de Fabricação – PMR – EPUSP – Av. Prof. Mello Moraes, 2231 – 05508.970 S.Paulo - gilmar.batalha@poli.usp.br

ABSTRACT: *The Ultrasonic Spotweld Inspection Technique presents nowadays a strong application in the automotive industry, due to its high speed test, automation capability, sensible cost reduction and automatic evaluation. However, one of the biggest issues of this technique is the high level of training required to the operators, to identify and understand the metallurgical concepts involved in the test, concepts that establish the automatic evaluation of the equipment. Thinking about this, the paper consists in verify, supported by metallographic, fatigue tests and FEM (Finite Element Method) analysis, the understanding of the ultrasonic signals through a metallurgical view, helping the operators to have a better understanding of the technique. This way, it became possible to the operators and programmers detect the probable process imperfection cases, using nondestructive inspection, increasing the reliability rank of the body in white production compared with the former destructive tests.*

Keywords: ERSW, Spotweld, ultrasound, metallography, BIW

1. INTRODUCTION

Sheets used in automotive bodies can be joined through spot welds, obtained from heat generated by electric current passed through the sheets by electrodes under a certain pressure. The heat causes a local melt of the sheets, causing the spot weld formation. It's a very popular process in the automotive industry, where we have huge operational costs involved, especially to guarantee these spotwelds quality, since in most of cases we have safety parts joined by this welding process.

This way, ultrasonic spotweld inspection is increasing in this field of industry, because it reduces the scrap of the parts, since it's not necessary to destroy the part to have the test results, besides increasing reliability of the tests.

The ultrasonic technique [1] is used in spotweld joints to determine these indentations, through the measure of the medium thickness of the spots.

This technique has the first experiments dated about 1986, in Germany, and it differs basically from the conventional technique by the use of a special transducer, that possess a water column between the piezoelectric crystal and the piece to be tested, eliminating the undesirable effect of the "dead zone", defined as the area of strong turbulences in the end of the transducers, disabling the measurement of small thickness.

The technique consists basically on a non-destructive test, where the equipment generates an electric pulse to a piezoelectric crystal that receives the pulse and vibrates, generating sound waves in the range of 0.5 up to 30 MHz, inaudible for the human being. Those waves penetrate in the material to be tested, and they contemplate when finding the bottom of the piece or any other reflector, generating signs that are amplified properly and after codified, exhibited in graph form or image, making possible to an operator properly trained the identification of which signs represent a eventually flaw in the material.

2. GOALS

The main goal of this paper is to present a “reading” of the A-scans echoes, through a correlation between Non Destructive Testing (NDT) and the correspondent metallurgical defect found in every case tested.

3. EXPERIMENTAL PROCEDURE

Starting from lower carbon steel sheets of 1.5 mm thickness, with the chemical composition showed in the table I and the nominal mechanical properties showed in the Table II, 3-point joints were obtained in specimens of 50 width mm and 110 mm length, as showed in Illustration 1.

Table I. nominal chemical Composition of the studied steel .

Element	C	Mn	P	S	Al
weight %	0,08	0,45	0,03	0,03	0,02

Table II. Mechanical properties of the studied steel.

Modulus of elasticity (GPa)	207
Yield strength (MPa)	195
Tensile strength (MPa)	304
Total elongation in 50 mm (%)	49.2
Hardness (HV)	100

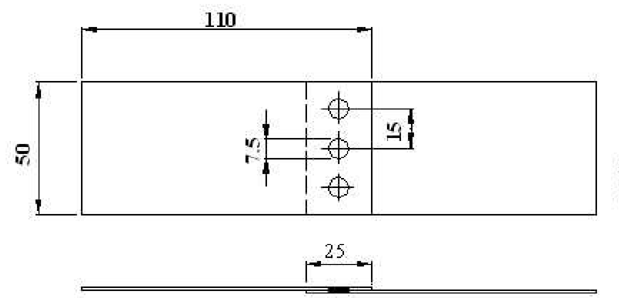

Illustration 1. Welded specimen in study and spot weld geometry.

These samples were used to perform these spotwelds, each one with its own welding parameter, to obtain a series of possible defects that we can found in a common spotweld, which we used to classify as good spot, loose spot, stick spot, flaw in the spot/small nugget and burnt spot, as we will show detailed below.

The welds samples were tested by ultrasonic inspection, using the Scanmaster UPI-50 spotweld inspector equipment, with a 20 MHz, 4, 5 mm diameter transducer with water column [2].

After the ultrasonic, the parts were submitted to the metallographic procedure, that were performed under standard conditions (cutting, polishing and etching on 2% Nital solution), and the specimens were visualized in a Leitz Laborlux 12 ME S optical microscope, where the images were acquired with a Nikon 5M digitalizing system.

4. RESULTS AND DISCUSSION

GOOD SPOT – As shown in illustration 2, is characterized by a short sequence of echoes, decreasing fast along the time. This effect occurs because the internal structure of this spotweld is coarse – grained (Illustration 3) and therefore has this sound attenuation characteristic, where the echoes intervals correspond to the total thickness of welded plates less the electrode indentation.

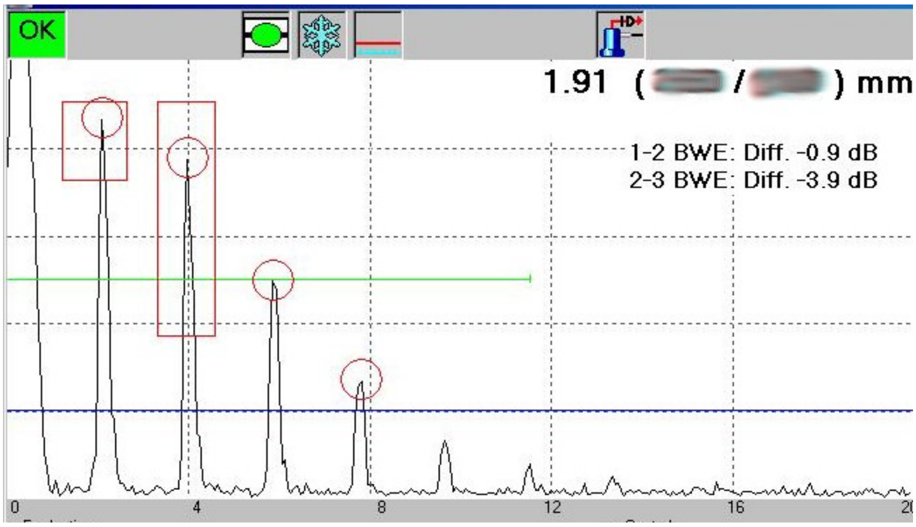

Illustration 2. A-scan representing a good spot.

Illustration 3. Macrograph of a cross- sectioned good spotweld

LOOSE SPOT – When the welding current and or pressure isn't sufficient, there is a chance to produce a loose spot, which can be defined in an ultrasonic inspection (Illustration 4) as a long sequence of echoes with short sound attenuation, where the intervals between echoes represents the thickness of the upper plate of the joint, just because we don't have the melted area in the middle of the plates.

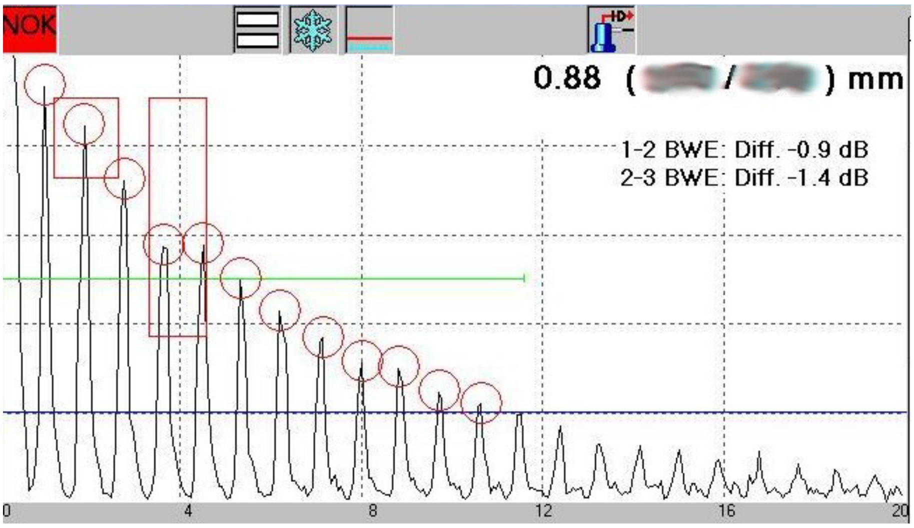

Illustration 4. A-scan representing a loose spot.

STICK SPOT – The welding parameter in this case is between a good and a loose spot, so there is a start of melting, but not enough to generate a well – formed spotweld. In ultrasonic (Illustration 5), it's defined as a short sequence of echoes with short sound attenuation, where the intervals between echoes represent the thickness of the whole joint, as illustration 6 shows.

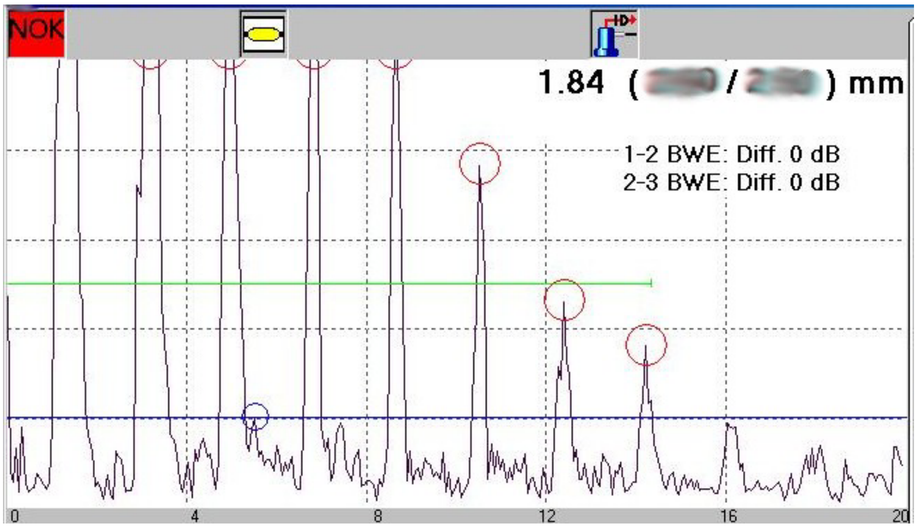

Illustration 5. A-scan representing a stick spot

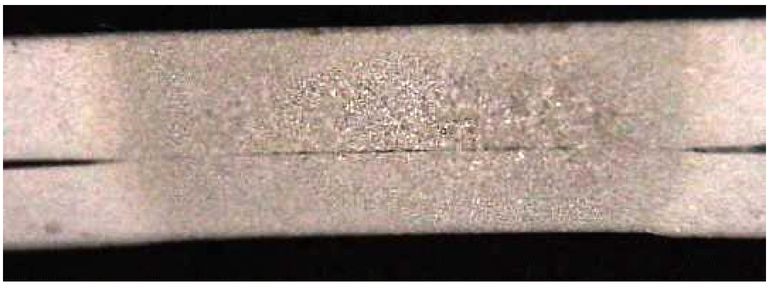

Illustration 6. Macrograph of a cross-sectioned stick weld

FLAW IN THE SPOT/SMALL NUGGET – May occur by a variety of events during the weld. In the particular case of the flaws inside the nuggets, can be caused by dust, oil or any kind of contaminant in the middle of the plates during welding. This strange particle interfere in the nugget formation, and generates a flaw inside the nugget, represented in ultrasonic like Illustration 7, and seen in macrograph as Illustration 8.

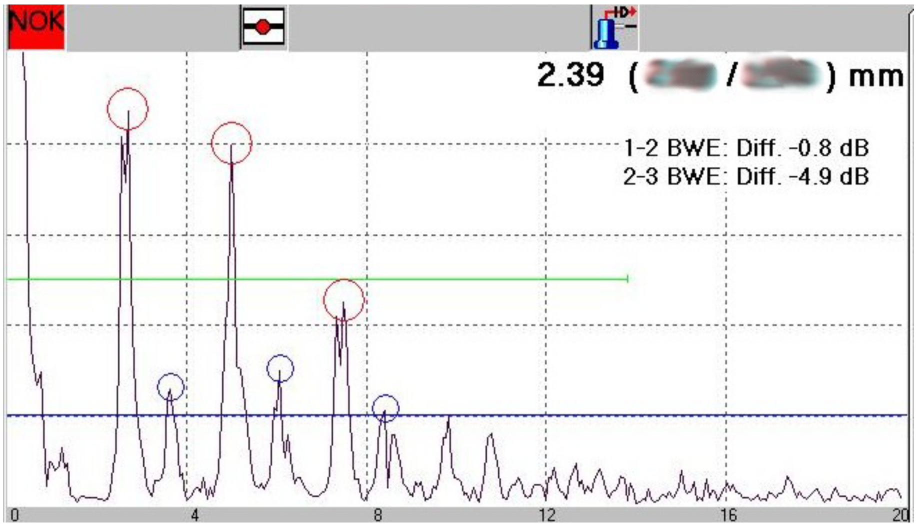

Illustration 7. A-scan representing a flaw in the nugget.

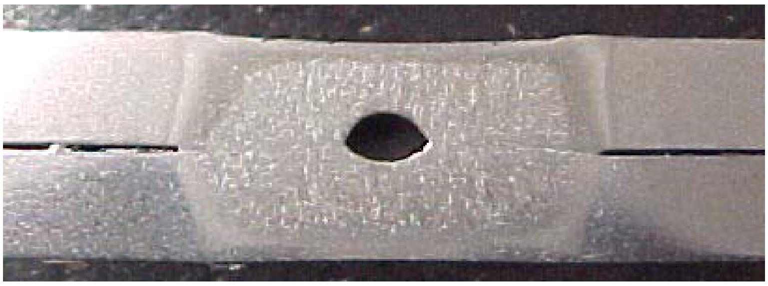

Illustration 8. Macrograph of the A –scan checked above representing a flaw in the nugget.

BURNT SPOT – Can be considered the highest difference between the former destructive test and the ultrasonic inspection. In a metallurgical approach, the burnt spot is a spot where the welding parameters were too high, generating an excessive melting of the nugget. Despite of the melting, which in the former tests could be considered as a good spot, this effect causes a series of undesirable effects, which are shown below. The A-scan is a very short echo sequence due to an extremely high sound attenuation, as illustration 9 shows.

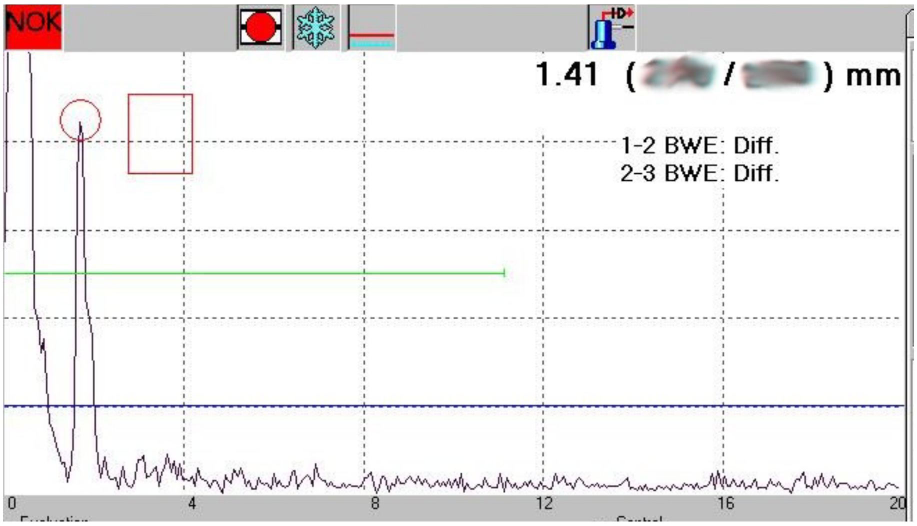

Illustration 9. Representative A-scan of a burnt spot.

One of the defects that may occur in this kind of spotweld is the deep penetration of the electrode, resulting in indentations in the sheet surfaces [3]; such indentations reduce the thickness of the welded joint locally and they can introduce stress concentration [4] in such joints, and this could reduce its fatigue life. One way of verifying the geometric stress concentrations due to these indentations is the finite elements method (FEM).

The FEM technique employed for spot weld joints simulation can be as simple as possible since the focus of the simulation is on the load transfer from one plate to another. In the present paper, metal sheets were simulated using Reissner-Mindlin plate elements without bending-torsion coupling. Normal and frictional contact between plates were simulated using simple adaptive gap elements. Loading transfer from one plate to another was simulated using a RBE-type approach where rigid and beam elements were combined. No effort in simulating residual thermal stresses resulting from thermal contraction was made since the RBE-approach is unreliable for detailed time-dependent stress and/or temperature analysis within the spot weld. Owed to the spot weld cooling is performed using fictitious temperature gradients based on experimental analysis or detailed simulations of the welding process such as in Lindgreen [5]. However, in the present analysis such procedure cannot be used because of the geometric variation owed to the electrode indentation in the sheets cannot be made using plate elements.

Microstructure – Illustration 10 shows a macrograph a burnt spot, where it’s possible to see a huge indentation in both sides of the joint, due to excessive heat and/or pressure of the electrodes. In illustration 11, it’s possible to see a top view of the spot, where it’s possible to observe, due to high temperature material from electrode surface deposited in the spot.

Illustration 10. Macrograph of a burnt spot.


Illustration 11. Top view of a burnt spot.

Besides these both effects , in some particular cases this excessive heat, combined with the pressure may cause some micro cracks in the surface of the spots (Illustrations 12,13), that combined with the electrode melting, causes the effects shown in Illustration 14, turning the spotweld brittle and unstable.

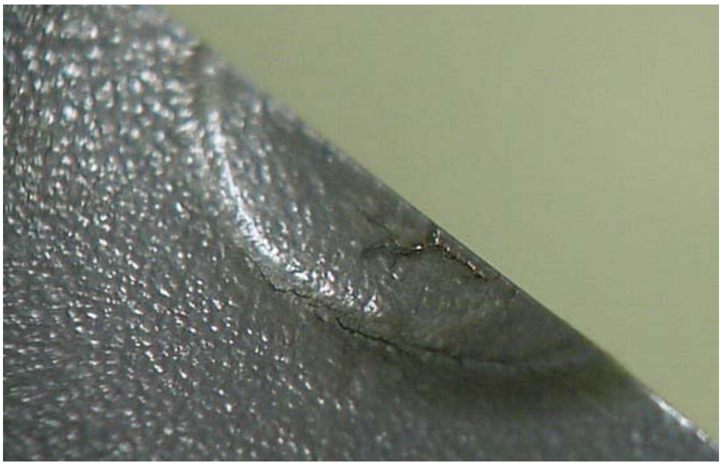
Illustration 12. Macrograph of a cross-sectioned burnt spot.


Illustration 13. Micro cracks found in a burnt spot (100X).

Illustration 14. Micrograph of a burnt spot, showing a copper deposit inside the micro crack (200 X).

Fatigue life – To prove such theory, a fatigue experiment [6] were performed to check if this burnt spot effects may cause a sensible reduction in the fatigue life.

The welding parameters were altered in order to obtain two different groups of samples, referenced to the spotweld indentation. The indentations were measured by ultrasonic technique .After this procedure, the welded specimens could be divided in two samples:

Sample A: specimens where the indentation did not surpass 20% of the joint thickness
Sample B: specimens where the indentation has joint thickness between 20% and 40%.

Both samples were submitted to a controlled cyclic load, varying it from zero to 14 kN, in order to determine the number of cycles to the fracture. Such tests were performed in an universal testing machine MTS, servo-controlled, of 250 kN of maximum capacity. The load reversion frequency in the tests was 8 Hz.

To FEM the time simulation was performed using 20 points by period for a frequency of 8 Hz for a total simulation time of 1.25s. These parameters correspond to 10 cycles of load application.

The results of this simulation with a mesh parameter of 0.8mm and non-structured meshes show that the stress developed inside the joint concentrates heavily near the external surfaces of the spot, fact experimentally validated. The results for mean (σm) and alternate ($\Delta\sigma$) von Mises stress obtained with zero indentation and solid modeling were 187 MPa and 192 MPa respectively. The results for plate modeling differ somewhat of those but exhibit the same pattern around the spot weld.. The results for plate modeling and solid elements simulation are presented in illustration 15 for mean and alternate von Mises stress. It is noticed that, for indentation levels between 0% and 15%, the results show a discreet elevation in the stress level and for an indentation between 15% and 50%, the stress levels increase more heavily, as illustration 16 shows.

Table III brings the medium values and respective standard deviation of the number of cycles to the fracture for the two samples, tested under constant load. It is noticed that the samples with indentations of up to 20% of the joints thickness result in life in fatigue of the sample 30% larger than life found in the sample where the indentation lies between 20 and 40% of the joint thickness.

Besides, it is noticed in this table that the standard deviation of the fatigue life of the sample with indentation up to 20% it is equal to 9% of the medium life, while for the sample where the indentation lies between 20 and 40% of the joint thickness the standard deviation corresponds to 35% of the medium life. Such facts show the deleterious effect of indentation increase in fatigue life of the components, and demonstrate that the parameter used in the ultrasonic measurements (to accept spots with up to 20% of nominal thickness reduction of the joints) for such spot welded joints guarantees better safety in the mechanical project against the former destructive tests used.

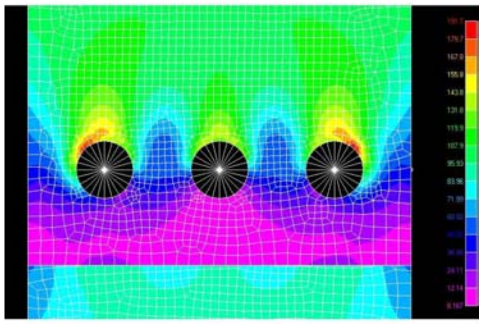

Illustration 15. Results of the simulation through FEM for the von Mises stress with plate elements, showing area of σmed concentration in the most external spots.

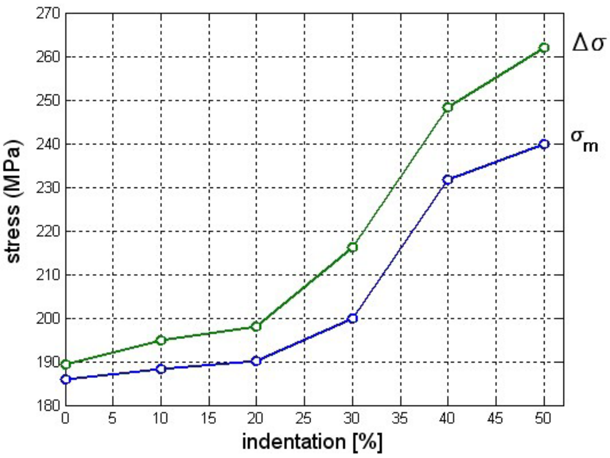

Illustration 16. Maximum main stress components variation in function of spotweld indentation. Results of the simulation through FEM with solid elements.

Table III. Medium values and respective deviation-pattern of the number of cycles to the fracture for the two groups of samples, tested with loads from zero to 14 kN.

Sample groups	Fatigue life (cycles)
Up to 20% of nominal thickness joints reduction	24663 ± 2316
From 20% to 40% of nominal thickness joints reduction	18935 ± 6647

5. CONCLUSIONS

Of the present work can be ended that:

- Used with criteria, ultrasonic inspection has a high reliability rate, and its results are very close to metallographic examination;
- It allows detecting even spots that has a significant life reduction, when submitted to fatigue;
- Installed in production lines, is able to predict flaws and guide the welding process;

- It's strong recommended that exists, at least in technique implementation phase, a metallographic guidance to the ultrasonic inspection, working as a technical support.
- FEM is a powerful tool in stress determination in structural elements that allows determination of the variation in time of stress found in complex geometries. Besides, the current results of the FEM were, at least qualitatively, experimentally proved, considering the low residual stresses found.

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CARACTERIZAÇÃO DE DEFEITOS EM SOLDA A PONTO POR RESISTÊNCIA ELÉTRICA POR INSPEÇÕES COM ULTRA-SOM E SUA INTERPRETAÇÃO METALOGRÁFICA.

Danilo Stocco
DaimlerChrysler do Brasil Ltda - Centro Tecnológico – Av. Alfred Jurzykowski, 562 – 09680.900 São Bernardo do Campo – SP - danilo.stocco@daimlerchrysler.com

Gilmar Ferreira Batalha
Lab. Engenharia de Fabricação – PMR – EPUSP – Av. Prof. Mello Moraes, 2231 – 05508.970 S.Paulo - gilmar.batalha@poli.usp.br

RESUMO: *A técnica de ultra-som em solda por resistência a ponto apresenta hoje em dia uma aplicação forte na indústria automotiva, devido a sua alta velocidade, potencialidade de automatização, sensível redução de custo e avaliação automática. Entretanto, um dos maiores problemas desta técnica é o nível elevado do treinamento requerido aos operadores, para identificar e compreender os conceitos metalúrgicos envolvidos no teste, conceitos que estabelecem a avaliação automática do equipamento. Pensando sobre isto, este trabalho consiste em verificar, apoiado em ensaios metalográficos, de fadiga e análise de MEF (Método dos Elementos Finitos), a compreensão dos sinais ultra-sônicos com uma visão metalúrgica, ajudando os operadores ter uma melhor compreensão da técnica. Desta maneira, tornou-se possível aos operadores e os programadores detectarem as imperfeições do processo de soldagem,*

utilizando a inspeção não destrutiva, aumentando o índice da confiabilidade do processo de produção de carrocerias brutas, em comparação aos testes destrutivos anteriormente realizados.