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Comparison between in - line ultrasonic monitoring of the spot weld quality and conventional NDT methods applied in a real production environment

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Abstract

Real-time spot weld characterization using ultrasound is a reality in today's automotive industry. The main goal of such testing systems is to reduce operational time and provide reliable means of quality inspection. Currently, several R&D groups are working to develop real-time ultrasonic system for spot weld quality monitoring, because potentially it allows one to eliminate expensive destructive tests, reduce the amount of off-line ultrasonic inspections and ensure the inspection quality.

The purpose of this paper is to analyze preliminary results of a single in-line ultrasonic station, installed at a real body-in-white plant condition, and perform a comparison of these results with the conventional quality assurance methods currently used at the plant, such as ultrasonic inspections (manual equipment strategically placed in the welding line), destructive (tensile tests) and metallographic tests. The results obtained from this comparison can show us if it is possible to apply this new technique in a real production environment, with the same reliability that we are used to experience in our current inspection structure.

It is believed that the obtained results will provide more flexibility for the plants to work with available ultrasonic inspection equipment, will increase the reliability and the control in the most critical regions of the bodies and will also decrease the inspection time during production.

Keywords: in-line, spotweld, ultrasound.

1. Historical Background

Metal sheets used in autobodies [1] are usually joined with the spot welds. The spot welds are formed during spot welding process. This process employs the electrodes which squeeze the plates under certain force and conduct high electric current through them. The Joule heat melts the base metal and forms a fused area which holds the sheets together.

Even though this is very popular and reliable method of sheet assembly, it involves huge operational costs connected with post-production inspection of the joints. The manufacturer needs to make sure the quality of the welds is good especially when talking about the safety welds. The most popular nondestructive methods for weld quality inspection employ different kinds of ultrasonic devices. The 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.

Currently the car manufacturers had developed several systems to monitor and measure these spotwelds nondestructively, and the real-time spot weld [2] inspection is a hot topic in today's automotive industry as it provides flexibility in production, ability to test 100% of the welds and thus reduce costs and losses on energy, materials and manpower. Such systems could eliminate or considerably reduce the post-production selective inspection, reduce the number of destructive tests and increase reliability of the assembly process.

Currently, this particular plant where the tests were made uses ultrasonic inspection to check in a statistical way some key spots of the body, using manual equipment, and once in a while a whole body is sent for a complete tear-down.

2. Ultrasonic inspection

The ultrasonic technique [3] is used in spotweld joints to determine the weld quality, through the measure of the medium thickness of the spots, and an interpretation of some A-scans provided by specific software.

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.

3. RIWA method

The approach uses the ultrasonic waves which pass through the spot weld structure during welding [4-9, 10]. On their way through the setup the waves are modified by the media and thus carry some information about the processes taking place inside the system. The setup consists of an ultrasonic transducer incorporated into the electrode of the spot welder. The ultrasonic transducers are driven by pulser-receiver; the last is controlled by the computer. The schematic view of the setup is presented in fig. 1.

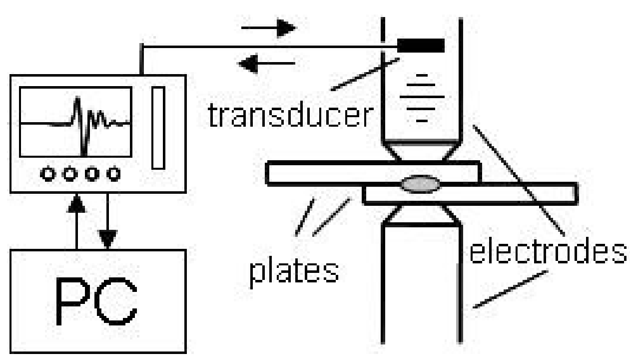


Figure 1. Schematic view of the experimental setup.

The specially designed ultrasonic transducer is incorporated into the gun electrode. The cooling water runs through it and the water flow pattern is not modified. The transducer uses cooling water to conduct the ultrasonic waves to the welding cap. Then, the waves run through the copper layer of the cap and penetrate into the welded plates.

There are two possible modes in the given setup – transmission and reflection. Although the transmission mode is somewhat more advantageous from signal-to-noise point of view it can be used only in the lab environment and proved unpractical when tested on industrial floor. The reflection mode provides the possibility to employ a single transducer working as both transmitter and receiver of the ultrasonic waves. Also, the information obtained with the reflection mode is very different from what can be received in transmission mode. The most important thing is that it provides the possibility to visualize the interior of the weldment. Specifically, it allows one to see the nugget size within the welded plates and locate its position relative to the faying interface. The transducer installed at the upper shank of the weld gun is shown in fig. 2 (a).

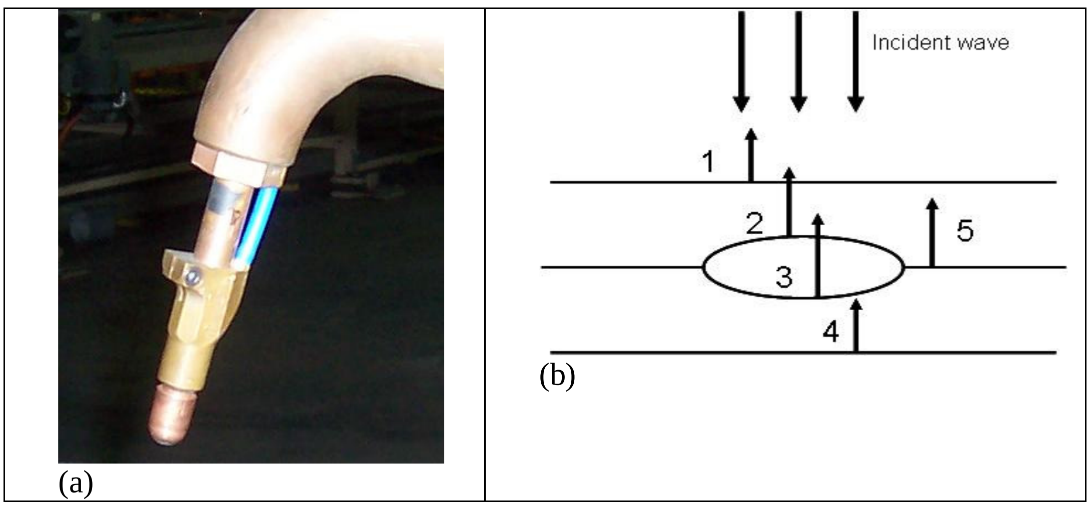
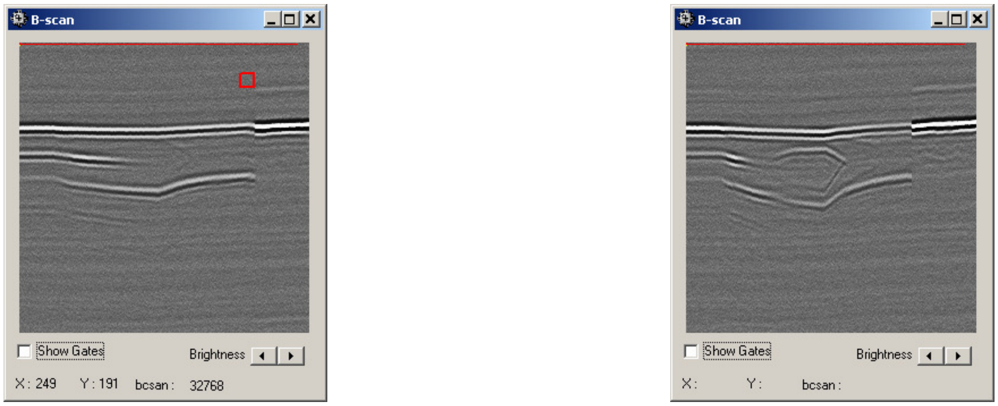


Figure 2. (a) – the ultrasonic wave penetrating the weld area; (b). the typical A-scan received from the weld.

As the wave passes through the welded plates in the direction perpendicular to the plate plane it encounters a series of reflections from the interior welding, fig. 2(b). They are registered by the software in the form of the A-scans.

In the setup used, the ultrasonic pulses are sent one after another with a short time separation. When the A-scans are put together they form a 2-dimensional image of the process of weld formation. It is called an acoustical signature of the weld, sometimes, the B-scan or M-scan. We often call it a B-scan even though this term is more frequently used for mechanical scanning of the sample. As the waves are being sent through the weldment with a short time interval the picture of the weld formation pattern is generated, as shown at fig. 3.



(a) (b)

Figure 3. (a) – B-scan representing a stick weld; (b). the typical B-scan representing a good weld.

3.1 Capabilities of the method

The analysis of the signature allows one to determine whether the fusion took place between the plates or not. The time separation between the waves reflected from different boundaries of the weld is proportional to the physical distances between these interfaces. Based on the time of flight measurements, it is possible to tell the degree of penetration of the nugget into each of the welded plate and the thickness of the weld relative to the total stack-up thickness. These facts provide a quantitative measure of the weld quality and allow additional flexibility in qualifying of the joint. For example, according to some standards (which vary between different applications, plants and quality control philosophies) the minimum penetration of the nugget into the plate should be greater than 30% of the plate thickness. This requirement can be directly tested by analysis of the signature. Fig. 4 demonstrates the situations which often occur in practice and which can be visualized with our method. The symmetrical case (a), when two same-thickness, same-material plates are welded together. The nugget is located symmetrically and geometrical dimensions are as follows: d1 is the penetration level into the upper plate; d2 is the nugget thickness; d3 is the penetration level into the lower plate. In case the welded plates are different in thickness and/or material the nugget location could shift, fig. 4 (b). Our method allows detect these three geometric features of interest which is crucial in quality control. Other NDE methods which detect the presence of the nugget tell nothing about its location.

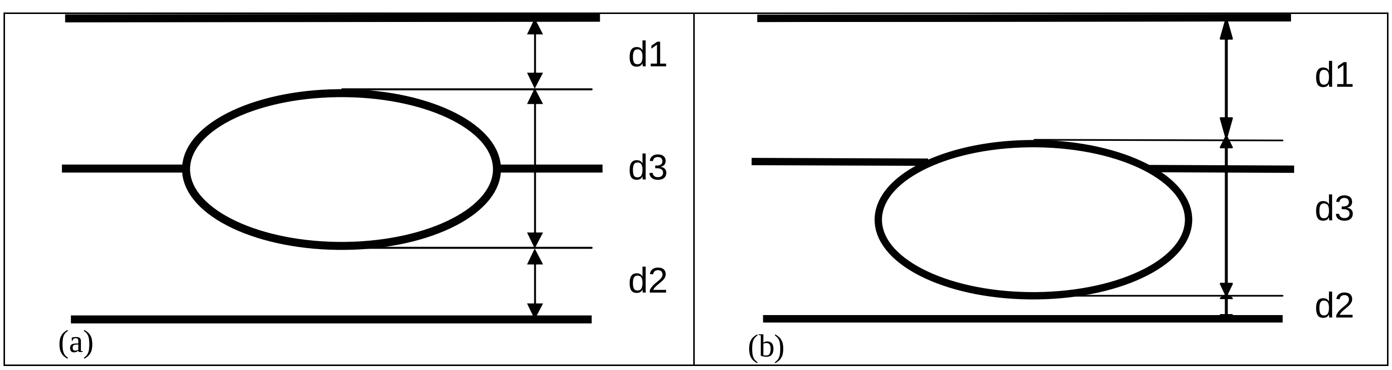


Figure 4. (a) – the symmetrical case of same-material, same-thickness weld; (b) – the non-symmetrical case, the nugget is shifted towards one of the welded plates making the joint weaker.

The automatic recognition of the pattern within the signature is the key element in automation of the process of quality control using this method. We have developed such an engine capable to recognize characteristic features on the noisy B-scan. Subsequent analysis of the extracted pattern allows the software quantify the weld. The process takes milliseconds after the weld is produced. The information about the quality can be used right away. There are two possible scenarios of using the obtained information: apply it for a monitoring system leaving it up to operator to make a decision about the given weld in the sequence, or, applying the obtained information within the closed loop algorithm capable of adjusting the welding parameters to cure the fault and produce the good weld on the top of the bad one or beside it.

The system tells the operator right after the weld is produced whether the fusion took place or not, how big the nugget is and what is the nugget location relative to the faying interface.

Since its first prototype, the ultrasonic transducer housing design has undergone several stages of modifications and improvements. Currently we have the transducer which can be easily installed at 70-80% of the applications. A coaxial cable connects the transducer with the standalone workstation which runs the transducer and processing/evaluation software. The workstation is capable of running several such systems on the neighbouring applications. The reporting protocol is developed to maximize the convenience of the operator to see the quality of the joints within a given part and also, within the sequence of parts produced previously.

A set of experiments has been performed on the study of the system stability during cap degradation and dressing. These are the factors which usually deteriorate the performance of different in-line ultrasonic systems. The extensive tests have been run on tip degradation. The ultrasonic signatures were acquired periodically during 3,000 weld trial. The system was able to recognize the pattern on the B-scan for all welds. Tip dressing was also a concern as long as many applications are using it today. Several pairs of caps were gradually dressed finally removing up to 9 mm of copper (severe dressing which was close to cap destruction).

The research in this field started in 1998 in the University of Windsor under the umbrella of NSERC and former DaimlerChrysler. Currently, the system has passed all laboratory tests and is on the final stage of testing at three assembly plants (Chrysler, Mercedes-Benz and Magna), which are currently running the in-line ultrasonic system.

4. Experimental procedure

The In-Line monitoring system has been installed at the Sao Bernardo Mercedes plant at the light truck cabin floor application. The application employs KUKA robot and Medar 3000s weld controller to put 330 weld spots using 13 different weld schedules, including 2T and 3T stack-up combinations.

At the robot we have installed 1 In-line transducer, 5/8” shank taper installed at the upper jaw, and also the Electronics in-line box and the SeaIO electronics box for weld ID signal, as shown in the illustration below.

The welded part is made basically of lower carbon steel sheets, from thicknesses ranging from 0,9mm up to 2,5mm, with an average chemical composition shown in the table I and the nominal mechanical properties showed in the Table II.

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

The spotwelds were performed in the part, each joint with its own welding schedule, and the a-scans and B-scans signals were acquired in-line to study the behavior of the system. After these tests, the part was tested by ultrasonic inspection, using the Scanmaster UPI-50 spotweld inspector equipment, with a 20 MHz, 3,6mm diameter transducer with water column [2], as shown in the illustration below.

After ultrasonic inspection, 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.

5. Results and discussion

Double-impulse welding schedule is used at the plant. Correlation for ultrasonic Time of Flights is currently unacceptable for such mode as the first pulse softens the welded area. At the moment, we can not provide quality characterization of the welds produced with double-pulse weld schedule. Additional research will need to be conducted to address double-impulse weld regimes.

We ran correlation test for selected welds within the part. For two different schedules, the 2-impulse mode was replaced with 1-impulse mode and correlation was performed for those welds.

We selected 14 spots with good alignment and welded some of them with regular current, some of them with lower current.

The next table shows the main values found at the correlation tests:

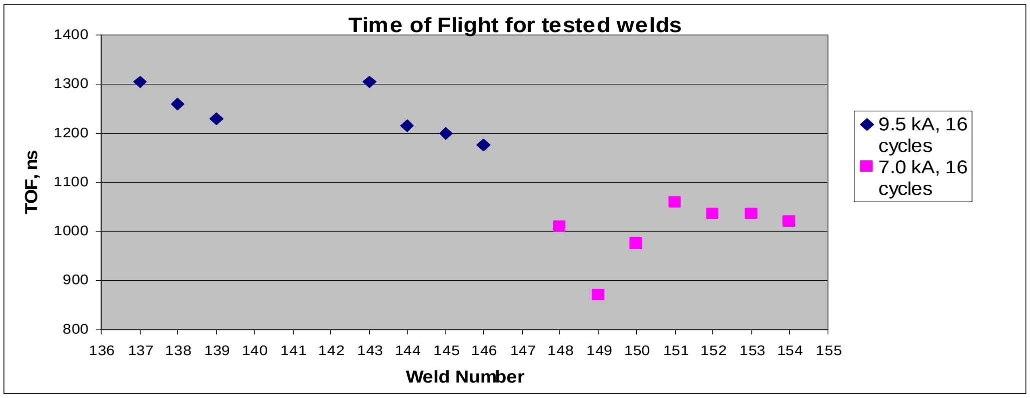


Figure 5. (a) – the symmetrical case of same-material, same-thickness weld; (b) – the non-symmetrical case, the nugget is shifted towards one of the welded plates making the joint weaker.

Table III. Results of correlation tests.

Weld ID	In-Line TOF	Metallography	UT-mate
137	1305	6,5	OK
138	1260	6,2	OK
139	1230	6,2	OK

143	1305	6,6	OK
144	1215	6,6	OK
145	1200	6	OK
146	1175	6	OK
148	1010	2,6	Undersized
149	870	0	No weld
150	975	0	No weld
151	1060	3,2	Undersized
152	1035	3,8	OK
153	1035	3,8	OK
154	1020	3,3	Undersized

These preliminary results have shown a correlation of 87%. It is high enough correlation to distinguish well between the good and undersize welds.

Currently, some instability in weld signature quality is observed from part to part for many spots. In other words, at some specific location, the weld signature on one part can be of high quality while on the following part, the signal quality is low. One of the possible reasons can be large size of the part and thus part shaking or wobbling during welding.

There are also some problems due to the excessive overheating of the cooling water and signal disappearance at the second half of the weld, probably due to the different materials applied at the shanks, issue that is being solved.

6. Conclusions and further plans

After the analysis of these preliminary results, we have come to the following conclusions:

- In a first sight, the IWA system can easily detect any deviation in the welding process, with some major advantages when compared to our current inspection procedure (manual US stations in strategic locations in the body shop);
- It will be necessary to run some correlation tests regarding 3 thicknesses joints;
- Additional research will need to be conducted to address double-impulse weld regimes;
- Cap degradation and the effects in the ultrasonic signals must be studied in the future.

7. References

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