Ultrasonic inspection of adhesive joints using flexible linear arrays

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Abstract

The inspection of adhesive joints is generally performed destructively, although attempts for a non-destructive inspection have been made in the past. Destructive tests produce scrap costs and cannot be performed close to the process, thus a timely feedback to the production lines is not possible. To provide a non-destructive quality control of adhesive joints, which can be directly applied at all stages in the manufacturing line, a novel ultrasound solution for testing of adhesive joints has been developed. Due to the complex geometry of the inspection part, a new flexible linear array probe design has been developed. The probe can adapt to convex and concave geometries to follow the contour of the inspection part, and covers up to 32 mm in electronic scanning direction. To assess the quality of the adhesive joint, it is crucial to record the full C-Scan. Quality criteria for adhesive joints are for example the minimal width of the adhesive, the percentage of the bonded area or the detection of voids and canals. Such quality criteria can be directly deduced from the inspection system. Extensive trials and verification tests on hemming joints in the automotive industry have been performed to prove the functionality of the inspection system.

1. Introduction

Within the last years adhesive joining technologies have become more and more important as a joining technique in different industries. This development is driven by an increasing usage of multi material combinations in light-weight construction, for which conventional joining technologies cannot be applied. In addition, the adhesive adds to the overall structural strength of the components. For frame-and-body construction in the automotive sector such adhesive joining technologies are used in hemming joints as well as structural joints of the car body. Such adhesive joints must be inspected to meet the high-quality requirements. The inspection approach is also applicable to multi-material combinations like metal composite combinations which are joint by adhesive layers. Hence, this inspection technology is not limited to the automotive industry.

2. Inspection of adhesive joints in the automotive industry

2.1 Destructive testing

Destructive testing is the most common inspection method for assessing the quality of adhesive joints in the automotive industry. Although this method provides a very accurate inspection result, it has several drawbacks. The testing method produces scrap costs and involves a work load to open the joint and perform the analysis. Since this inspection can only be performed after curing of the adhesive, it cannot be performed close to the process and a direct feedback to the production line in case of detected defects is very limited.

2.2 Penetrant testing

Penetrant testing also produces scrap costs and lacks the ability to provide direct feedback to the production line due to the expenditure of time of curing the adhesive, applying the penetrant liquid and opening the joint.

2.3 Ultrasonic testing

Conventional ultrasound inspection of adhesive joints has been used in the automotive industry within the last years. However, due to the limit size of the ultrasound transducer only a spot-wise inspection is possible, such that typically only a low percentage of the adhesive area can be inspected in a production environment. Moreover, only an imprecise defect sizing is possible. The benefit of the ultrasonic testing method is, that it can be performed close to the process such that direct feedback to the production line is possible.

3. Testing of adhesive joints by means of ultrasound

The principle of ultrasonic inspection of adhesive joints is illustrated in figure 1. A typical scenario is that two metal plates (A and B) are joined by an adhesive or glue layer. If an ultrasonic probe is placed on top of plate A in an area where no adhesive is present, the ultrasound will bounce back and forth within the plate producing a long backwall echo sequence in the A-Scan. This long backwall echo sequence is the indication that no adhesive is present at the current inspection point. In contrast, if adhesive is present at the current inspection point, a small portion of the ultrasound energy is transmitted into the adhesive layer where it is absorbed. This absorption of ultrasound energy leads to the effect that the backwall echo sequence becomes shorter, meaning less repetitions of the plate thickness are observed at fixed instrument gain settings. This reduced backwall echo sequence is an indication that adhesive is present at the current inspection point. It should be noted that this inspection principle can only detect whether the adhesive is present at the backside of the plate from which the inspection is performed. To make an assessment whether the adhesive is also present at the backside of the second plate an inspection from the surface of that plate must be performed.

4. Inspection of adhesive joints using a flexible linear array

One of the main applications for inspecting adhesive joints in the automotive industry are adhesives in hemming joints. The adhesive serves as a structural component to join the two metal sheets and acts as a sealant to prevent water ingression. In the case of hemming joints, a non-defective adhesive joint is characterized by a minimal width of the adhesive line along the hemming as well as a minimal total bonded area integrated over the full length of the hemming. In addition, the adhesive line should not have any larger voids with lack of adhesive or canals running through the adhesive which would lead to water ingression and thereby to corrosion of the part.

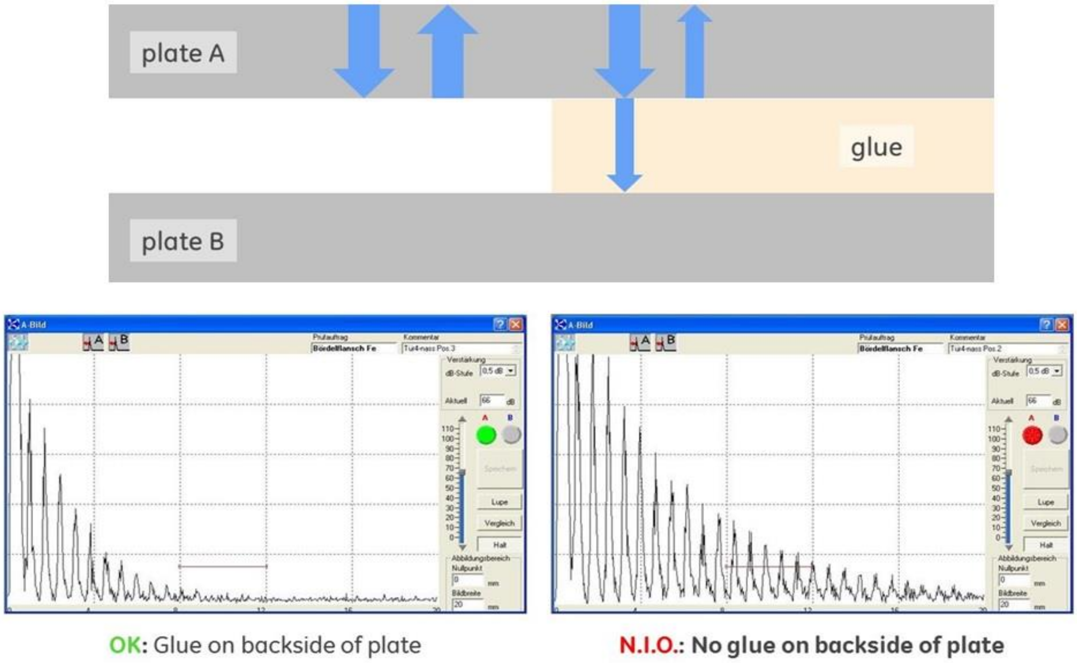

Figure. 1. Ultrasonic inspection principle. Ultrasound is transmitted into one of the plates and based on the length and or amplitude of the backwall echo sequence an assessment can be made, whether adhesive is present on the backside of the plate being inspected.

To be able to deduce the relevant parameters for assessing the quality of the adhesive joint, the ultrasonic probe needs to cover the full width of the adhesive line and the ultrasonic inspection system needs to record the position of the probe on the part to generate a C-Scan image of the adhesive distribution. To fulfil these requirements, a linear array probe has been developed in which single elements can be grouped electronically to an active sub-aperture. This sub-aperture is then propagated electronically along the length of the array, such that the full width of the adhesive line is covered without losing information. For each sub-aperture step the A-Scan data is evaluated to determine whether adhesive is present at the current inspection point or not.

Due to the complex geometry of the inspection parts when inspecting from the top sheet of a hemming joint (which can be concavely or convexly shaped) an innovative flexible linear array probe design has been developed. The flexible probe can adapt to the contour of the part up to a curvature radius of 80 mm whether it be concavely or convexly shaped. In addition, a positional encoder is mounted to the probe such that the inspection data can be recorded with millimetre precision and accurately mapped on the inspection system while scanning along the hemming. The current probe design can cover a width of 32 mm either with a total of 32 or 64 elements and operates at a frequency of 10 MHz. Figure 2 shows the flexible array probe positioning when inspecting an engine hood hemming.

The inspection result from the 2D measuring grid (electronic sub-aperture propagation and encoder position) are displayed in a colour coded C-Scan on the ultrasonic inspection instrument such that the inspection result is correlated accurately with the part being inspected. The inspection data is generated in vertical direction by the electronic propagation of the sub-aperture and in horizontal direction by the mechanical movement of the position encoder.

Figure. 2. Inspection of an engine hood with a flexible linear array in direct contact.

Figure 3 shows a strongly scaled C-Scan (recorded length approx. 1000mm) of an inspected hemming on a car door. The lower edge of the C-Scan corresponds to the edge of the door hemming, and the vertical dimension of the C-Scan covers the adhesive line and partially an area of the bare top sheet at the top of the C-Scan. Areas depicted in red colour indicate areas in which no adhesive is present, whereas areas depicted in green colour indicate areas in which adhesive is present. The C-Scan was recorded on a reference door in which artificial defects were present. The artificial defects were: (A) a defect starting from the lower edge of the hemming and reducing the width of the adhesive line; (B) a defect simulating a reduced width of the adhesive line starting from the top bare sheet and (C) a canal running though the full width of the adhesive line. A larger natural defect (D) which reduces the width of the adhesive line like defect (B) could also be identified. In addition, multiple small natural defects can be identified across the width of the adhesive line. In the first quarter (around 100 mm – 200mm) of the C-Scan, a larger void of missing adhesive can be identified in the centre of the adhesive line. The top contour of the adhesive line can be monitored over the full length of the adhesive line. As the C-Scan provides position and resolution information, parameters like width and length and by these the area of an indication or the overall width of the adhesive line can be read-off the screen of the inspection system by the operator in real-time.

Figure 4 shows three C-Scan images from a car door taken out of the production line. Starting from the upper left corner, small voids in the adhesive line can be identified while the rest of the hemming shows an evenly distributed adhesive. The red indications at the bottom of the C-Scan show missing adhesive in the area where the top sheet is hemmed around the inner sheet. Since the adhesive line does not show any canals, there is no risk of water ingression such that these indications are not considered to be defective. In the C-Scan of the bottom hemming, only a few small indications are observed which indicate small voids of missing adhesive. The right C-Scan shows some elongated indications which are close to the lower edge of the hemming, albeit being located more towards the centre of the adhesive line. Such indications would need to be evaluated based on elongation and area to judge whether these would result in a defective hemming joint. The direct evaluation of the C-Scan image by the operator allows a real-time assessment of the quality of the hemming joint which was not possible by using conventional ultrasound. Thus, the inspection system can be used close to the process and provide timely feedback to the production line in case of detected defects.

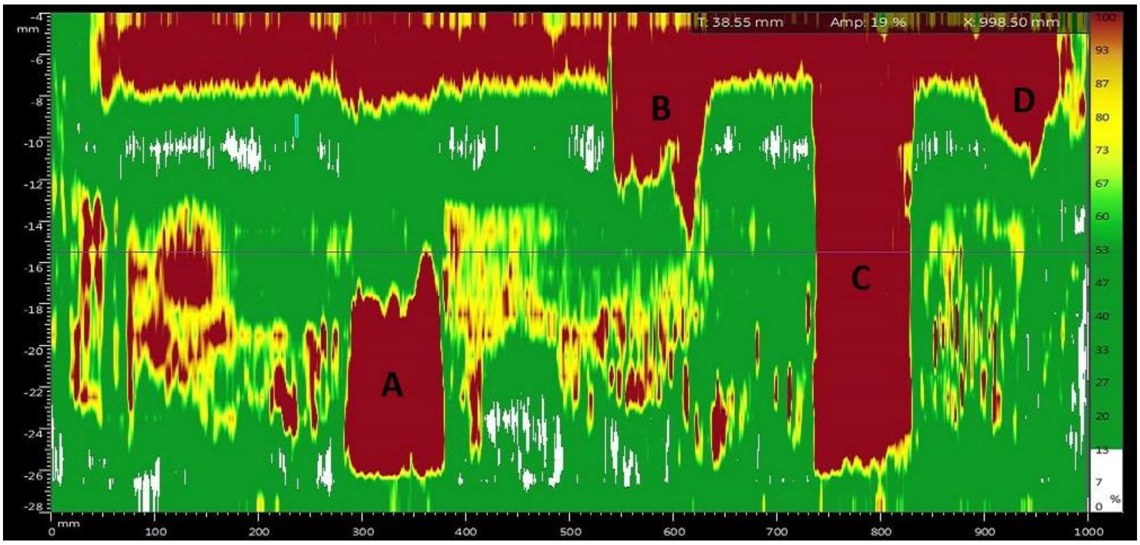

Figure. 3. C-Scan Image of a hemming joint. The C-Scan is strongly scaled, actual scan length is about 1000mm. Areas displayed in red correlate with areas in which no adhesive is present in the hemming while areas displayed in green image the distribution of the adhesive in the hemming.

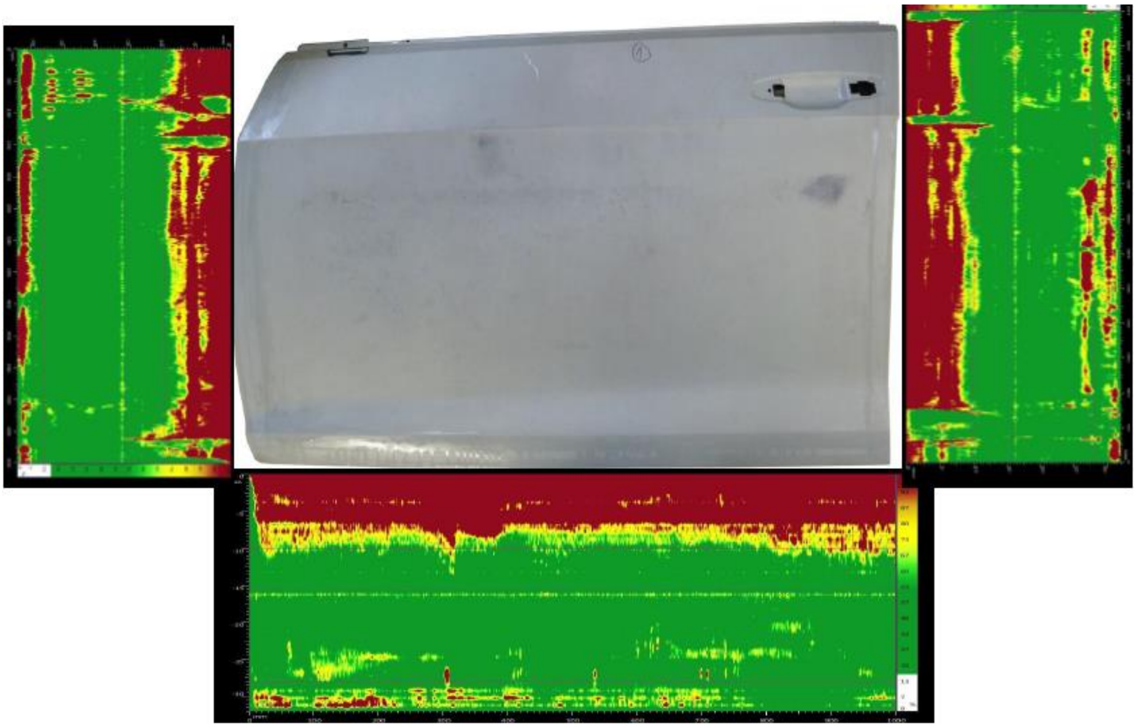

Figure. 4. C-Scan images of car door hemming. The C-scans are strongly scaled. The ultrasonic C-Scans represent the distribution of the adhesive in the different hemming on the inspected car door.

Due to the dimension and design of the flexible probe it is only suited for the inspection from the outer top sheet surface. To fully assess the quality of a hemming joint it may also be necessary to inspect the much shorter area of the top sheet on the bottom side of the hemming which is wrapped around the inner sheet. For inspecting these surfaces and structural adhesive joints of the car body different probe designs are currently under development.

5. Inspection system for adhesive joints

The full inspection system consists of an array probe suited to the inspection part and the MentorUT ultrasonic inspection instrument to record the data and display the C-Scan for evaluation by the operator. The MentorUT features a workflow based inspection concept which guides the operator through the single steps of the inspection and thereby significantly reducing the operator training time. Figure 5 displays the inspection system with the flexible linear array which is suited for the inspection of hemming joints.

Extensive trials and verification tests on hemming joints in cooperation with industrial partners in the automotive industry have been performed to prove the functionality of the inspection system**.** The inspection system has been validated by correlation of the ultrasonic inspection results with destructive tests which showed a high degree of consistency between the two inspection methods**.**

Figure. 5. Inspection system for adhesive joints. The inspection system consists of the MentorUT ultrasound inspection instrument and an array probe suited to the inspection part.

6. Inspection of adhesive joints in multi material combinations

The inspection principle and inspection system cannot only be applied to the inspection of metal sheet combinations as discussed in the paragraph 4, but also to multi-material combinations in which a metal sheet is joined with another material. In the current development stage of the inspection system reliable data is only provided if the material of the testing surface to which the ultrasonic probe is coupled is made of metal.

An investigated test specimen consisted of a titanium sheet which was joined with a composite base body by an adhesive layer. At the lower edge of the specimen the titanium was not glued to the composite base body. Foreign objects have been placed within the adhesive layer to simulate missing adhesive. Figure 6 shows the C-Scan of this titanium composite specimen which has been recorded with the flexible array. Due to the width of the specimen the C-Scan was recorded in two index steps to cover the full width. In the lower half of the C-Scan the contour of the bare titanium sheet displayed in red colour can clearly be seen. Above this contour the distribution of the adhesive is displayed in green colour. The artificial defects which have been placed in the adhesive can clearly be identified in the C-Scan as red indications and their size and position can be directly deduced from the C-Scan.

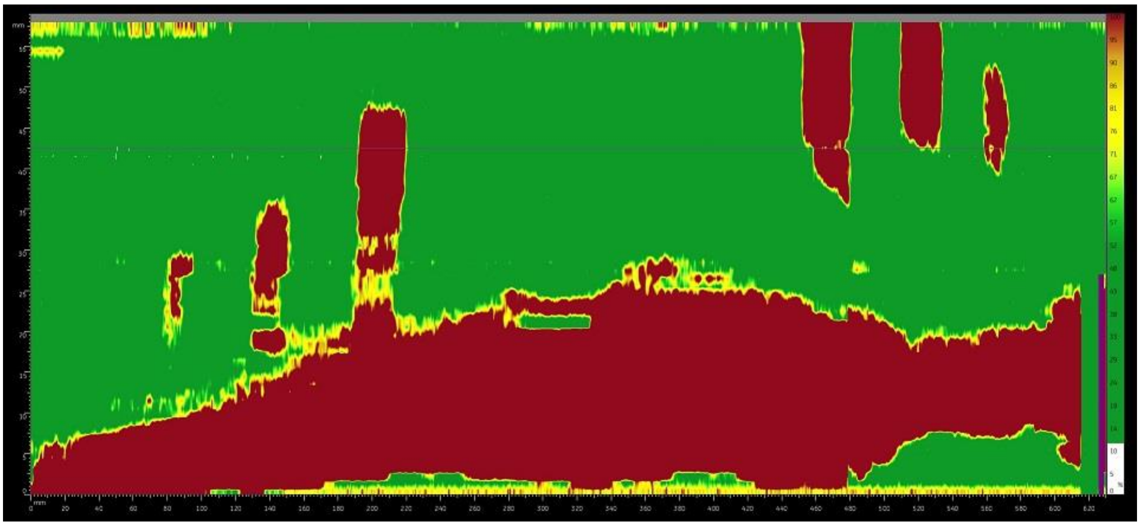

Figure. 6. C-Scan image of a titanium composite material combination. Areas displayed in red correlate with areas in which either bare titanium was present (red area starting from the lower edge) or the position of artificial defects which have been placed in the adhesive layer.

7. Conclusions

The inspection method and inspection system presented in this paper allow the inspection of adhesive joints in different applications. By employing a flexible linear array, images of the adhesive distribution can be recorded and detected defects can be clearly identified and sized, which was not possible with the conventional ultrasound inspection method. The ultrasonic inspection of adhesive joints offers large benefits with respective to destructive test since no scrap costs are produced and the inspection can be carried out close to the processes, such that corrective actions can be taken early in the production line if defects are detected.

Although the main application for developing this solution was focused on the inspection of hemming joints in the automotive industry, it can be applied to other applications like structural adhesives or even multi-material joints if one of the joined materials is made of metal. Inspection solutions for different part geometries and material combinations are currently under development.