NDT OF KISSING BOND IN AERONAUTICal structures

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Abstract: The lack of accurate methods for detecting kissing bonds is one of the reasons that prevent the larger use of adhesive bonding in the aeronautical industry. The main problem with kissing bonds is that their real nature is not well understood. By kissing bonds, one often describes a range of defects, which do not fit into any other better-defined category of defect. They represent disbonds with the two faces touching in some way.
This paper details a study carried out by CSM Materialteknik on the detectability of kissing bonds in adhesive joints and titanium diffusion bonds. Aluminium-epoxy-aluminium kissing bonds have been artificially manufactured following a procedure that firstly respects the standard way of bonding metal to metal at Saab AB, and secondly that respects the basic requirements for qualifying a kissing bond, e.g. adhesion failure under very low stress compared to the nominal stress. The manufacturing procedure is presented. Other kissing bonds produced with electrically releasing epoxy and also titanium diffusion bonds contaminated locally with oxygen have also been used. Different NDT techniques have been assessed such as Thermography, Shearography, NonLinear Ultrasonics, Classical Ultrasonics and Ultrasonic Resonance Spectroscopy (URS).

Introduction: Adhesive bonding is used in many applications at Saab. One of the problems with using adhesives is the occasional occurrence of “kissing bonds”, bonds in which surfaces are in intimate contact but with little bonding. These kissing bonds cannot be detected under classical NDE inspection techniques because there is no noticeable separation between the adherent and the adhesive surfaces. Therefore we are looking at a reliable mean of detecting them in order to enhance reliability and reduce costs. As partners in the INCA project [1] CSM Materialteknik AB and Saab have been investigating the potential of Ultrasonic Resonance Spectroscopy (URS).
The first step in order to assess such a technique is to develop a methodology for consistently producing controlled kissing bonds in test samples just as they would occur in the actual manufacturing environment.
Although it is not very clear whether kissing bonds really exist and what their exact nature is, there is a general agreement on the fact that their formation is linked to one or combination of problems at the surface such as the introduction of contaminants, e.g. fuel and hydraulic or de-icer fluids. However it has been shown by CSM [2] that most contaminants do not induce any weakness in bonds as long as they do not contain any silicone. Silicone based oils however do present a real danger since the strength of the bonds can be seriously altered. Therefore we developed kissing bonds by introducing a chemical surface modification in the standard adhesive bonding standard used at Saab. This method is at the present time applied only to metal-to-metal bonding, but at Saab we have identified the occurrence of kissing bonds in composite bonded parts and in the future a new protocol for the manufacturing of artificial kissing bonds in composite will have to be done.
After the protocol had been established and verified and samples had been produced, mechanical tests have been carried out to test the sample’s bond strength. The samples

that accurately simulate kissing bonds have been use to evaluate the URS NDE technique on its ability to detect kissing bonds.

This study is the first stage of a longer study whose aim is to produce an instrumentation based on the URS method, which would satisfy several criteria including portability, ease-of-use and ability to conduct on-field inspection of adhesive bonds. At this stage the general capabilities of URS are still being assessed.

Simulating kissing bonds: Many process factors can lead to the same flaw type, identified as a kissing bond, but they may not have the same origin. These factors can be surface contaminants, incorrect anodization or priming, or adhesive chemistry or cure processing, residual stress, moisture ingress or any combination of these or other factors. Therefore an ideal protocol for producing kissing bonds reliably is to tightly control all the factors that can affect the normal bonding procedure one should only introduce one change in this cvontrolled standard procedure.

Regardless of their origin defective bonds must exhibit certain characteristics to be regarded as possible reference samples for kissing bonds. These criteria although partly arbitrary, are derived form what we understand from the real nature of kissing bonds. These criteria are:

1. Their strength in a lap shear test must be below 20% of the nominal strength.
2. The mode of failure must be adhesive, that is purely at the interface between the adherent and the adhesive.
3. They must be undetectable from normal bonds with classical amplitude C-scans.

If kissing bonds are created by addition of some material at the interface between the adherent and the adhesive, it must be verified that this material did not migrate into either the adhesive or the adherent, what means that the properties of the adherent and/or the adhesive have been left unaffected. This condition is easy to verify with an ultrasonic C-scan. Similarly if a material is introduced, its thickness must be such that it is not detectable, which means that it must be much more thin than the adhesive layer.

Concerning the adhesive bonding of aluminium plates, we followed the Saab's standard [3] for aluminium bonding by hot cure. We used a Cytec FM73 film adhesive supported by polyester knit fabric scrim which control the flow and glue line thickness during cure. Bonding was carried out at 120oC during 90 minutes with bond line pressure maintained at 350 Psi. Such a bonding procedure has been used on the aircraft Saab 340 and Airbus A310 since 1982. The method we used to create kissing bonds from this standard procedure consisted in a chemical surface modification of one of the aluminium plate. In general such a method implies using complex tailored organosilanes to chemically modify the bonding between the primer and the adhesive layer. This process is very complex and difficult to control. So instead we used a simplified technique by introducing a dry layer of silicone in place of the primer. In this way the bond was very similar to a good bond but the adhesion strength between the adherent and the adhesive was reduced in proportion of the quantity of silicone introduced.

We also produced kissing bonds by using an electrically disbonding epoxy [4]. The properties of this epoxy are such that once bonded, it can be "unzipped" by applying an electric field. We experienced that despite a tight control of the applied voltage and duration of application, the resulting disbond was always too strong to be representative of a real kissing bond as we defined it. Therefore we used such samples bearing in mind they are in some ways the caricatural representation of real kissing bonds and therefore that the results obtained with the URS method on such samples are probably the showing the maximum sensitivity magnitude of that method.

The third method used for this study was to contaminate a titanium plate with oxygen over a small controlled region in order to alter locally the diffusion bond process and to create over the contaminated region a thin layer of hard alpha (or alpha case) molecules. Such an altered diffusion bond is not exactly a kissing bond as defined above but it still presents very similar mechanical properties, i.e. it is almost undetectable at frequencies below to 25MHz and the strength of the bond is low. So it is believed that such bonds are good materials for the assessment of the URS technique, although we must be careful when interpreting the results of such experiments. Figure 1 shows the titanium sample used in this study and the marked area in blue indicates the region that has been contaminated with oxygen. The C-Scan showed on the right side of figure 1 shows that the presence of the alpha case layer is undetected at 10MHz.

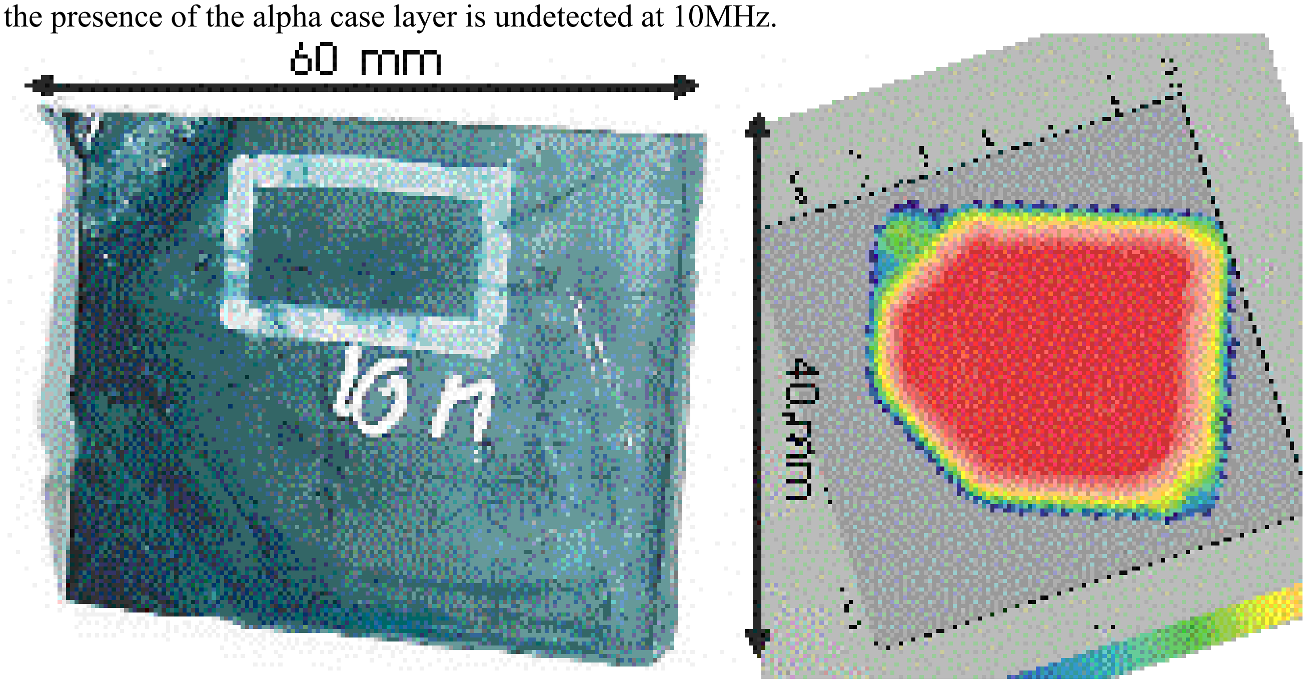

Figure 1: Titanium diffusion bond with indication of the positin of the alpha case layer, and the C-scan at 10MHz.

Shearography and mechanical testing: The difficulty with kissing bonds is that as good as the procedure for producing then, one is never 100% sure that the sample used is a kissing bond. The ultimate test is therefore a destructive lap shear static test. When proceeding to such a destructive test, a series of good bonds have been broken in order to establish an average strength value. Only samples that failed under a load equal or lower to 20% of the nominal load and that had a pure adhesive mode of failure have been classified as kissing bonds.

In the attempt to evaluate an NDE technique, much time can be wasted in testing samples that will not qualify as kissing bonds after the ultimate mechanical test is performed. Therefore it is beneficial to have a reference NDE technique that would be able to show some sensitivity to the bond strength. Shearography testing proved to have certain sensitivity to the bond strength under certain condition. With samples 75mm large, clamped on both sides, just after a sufficient amount of heat is applied at the surface of the bond, the weak bonds exhibit a larger surface displacement than the good bond and shearography results show that clearly, as shown in figure 2. The samples used were the bonds produced following the Saab's standard and introducing a given volume of silicone. The sample marked 0% is a good bond and the other ones have been contaminated with a given percentage of contaminant. It is seen that the more contaminant the more displacement difference is detected by the CDD camera.

Figure 2 also shows the results of the mechanical test for the same samples. It is seen that the more contaminant the less strength is required to break the samples. Above 24% the strength required is below 20% of the nominal strength and figure 3 shows that the mode of failure of the contaminated bond is purely adhesive (interfacial) whereas the mode of failure of the good bond (no contamination) is cohesive. Therefore it is believed that firstly, shearography can be, under certain condition, used to identify the bond strength and that our method to produce kissing bonds is efficient. Although not shown here, shearography ha also been able to detect the presence of the altered region in the titanium sample.

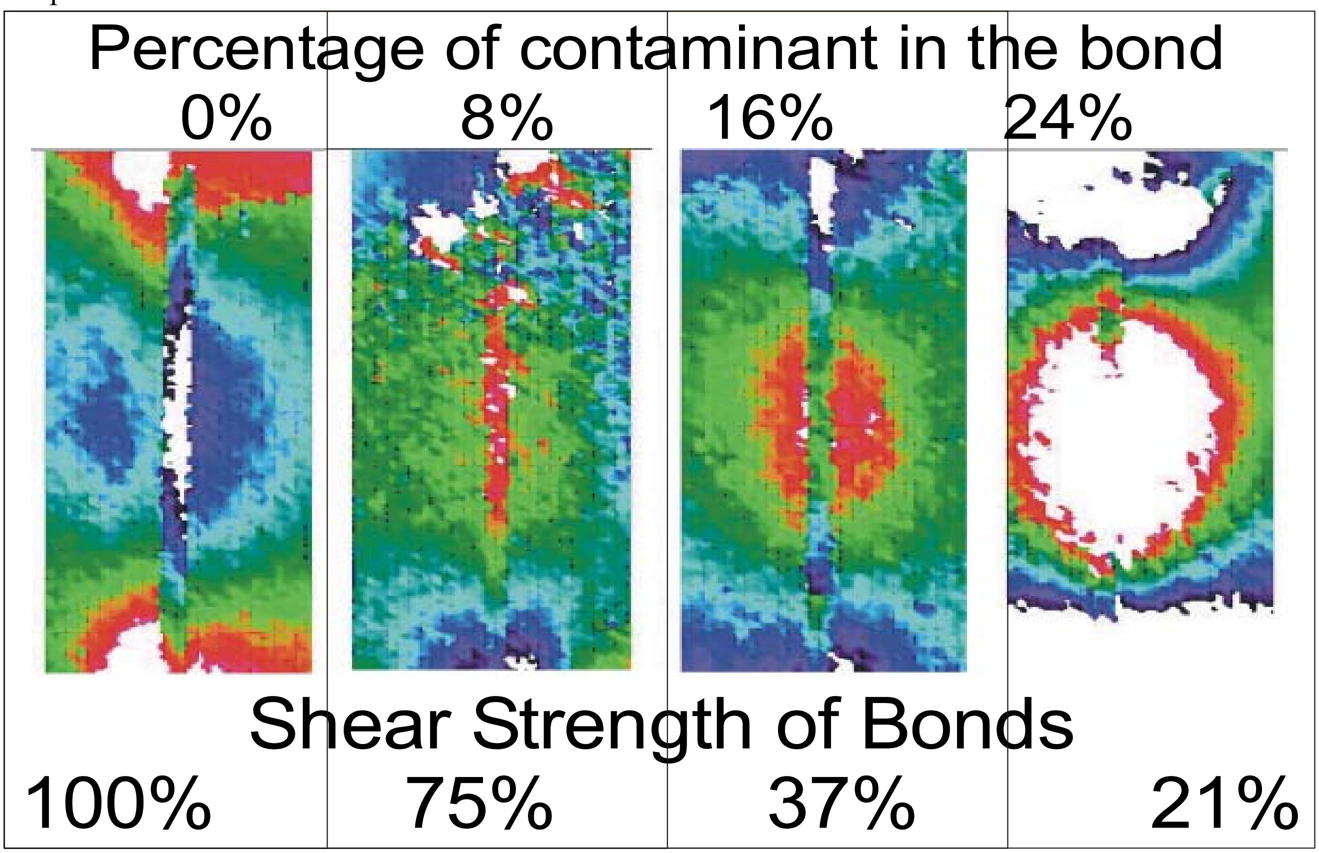

Figure 2: the shearography results and the results of the static mechanical test (in percentage of the strength needed to break the good bond) for 4 different bonds with various level of contamination.

Thermography: Infrared thermography testng has also been carried out on one set of samples.

Ultrasonic Resonance Spectroscopy: Ultrasonic resonance spectroscopy is simple technique that records the resonance of a given structure under ultrasonic excitation. Traditionally in the aeronautic industry, ultrasonic resonance testing are made using equipments such as the Fokker Bond-Tester and the Sonic Bondmaster. We carried out several tests but both the Fokker Bond-Tester and the Sonic Bond-Master (in single frequency mode) proved unable to detect the presence of a kissing bond. Such results are not surprising considering the very nature of the measurements performed by these two pieces of equipments in single frequency (or narrow band) mode, i.e. the changes in the resonances of the probe are recorded and displayed and the modes of vibration occur at low frequency since they are mainly governed by the probe. Therefore those equipments work well for unbonds and delaminations but since kissing bonds are by definition not totally disbonded but almost identical to perfect joints in all respects but with a low adhesion strength, it is not believed that such equipments can be sensitive enough to detect such changes in the adhesion strength.

In the other hand, very promising results have been obtained in large-band frequency mode, using separate transducers to emit and receive. The system we used is a broadband swept-frequency using a chirp tone burst to drive the emitter. The system captures the multiple reflections through the structure using one or two receiving transducers and the corresponding frequency spectrum are displayed on the screen. The system we used is the Quasar RI 2000 [5].

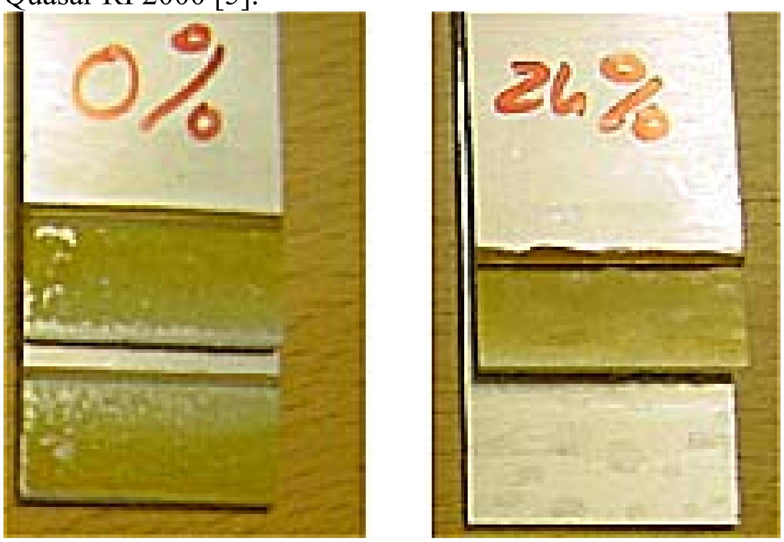

Figure 3: failure mode for the good bond (0% contamination) and the kissing bond (24% contamination).

Figure 4 shows the spectra obtained on the kissing bond manufactured by addition of a silicone-based contaminant. The spectrum for a perfectly good bond is shown in black while the spectrum of the kissing bond created by adding 30% of silicone-based contaminant is shown in red. It is readily seen that the amplitude of the spectrum is very much affected. However amplitude variation can be linked to many different factors difficult to control, for instance the thickness and the properties of the bond [6-7]. In the other hand, the degree of frequency shifts or doublet splitting, i.e. the frequency difference between the peaks as induced by the presence of the weak bond, are more easy to relate to the bond quality. Therfore the resonance peaks in the frequency range 1.4 to 1.6 MHZ are very interesting since they basically correspond to the resonance of shear waves and exhibit a large doublet splitting effect.

Variations in the resonances occurring in other frequency bands are also of interest but probably more difficult to interpret since they occur in frequency bands where several possible resonances can theoretically occur, i.e. longitudinal wave in the overall system, harmonics of shear wave resonances and/or longitudinal waves in a single layer, etc. Similar effect can been seen on figure 5 and figure 6 on the titanium bonds and the kissing bonds produced with the ElectRelease epoxy. As expected the differences are more noticeable on the ElectRelease samples since the kissing bond produced is extremely weak. However the results are very comparable qualitatively.

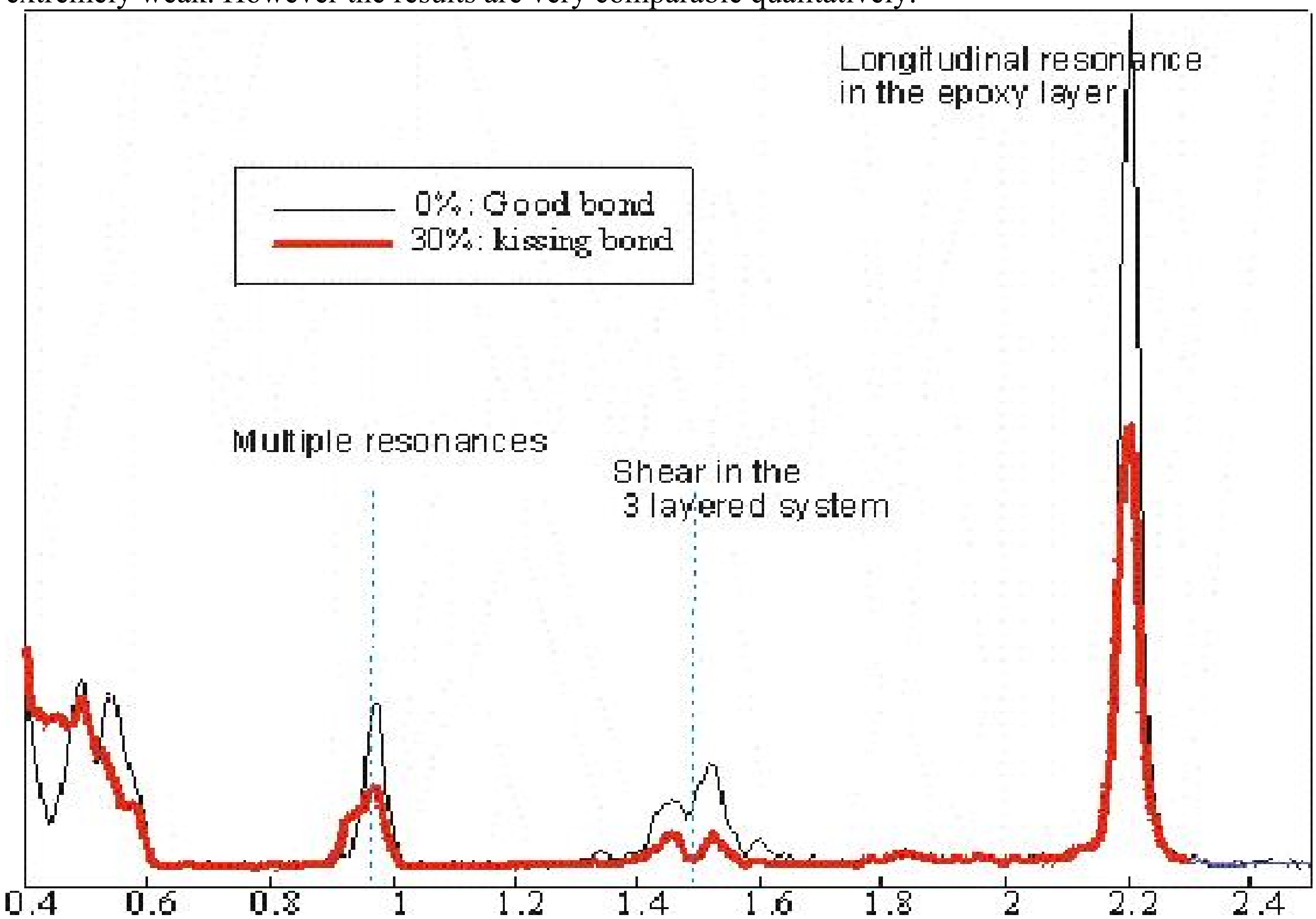

Figure 4: Spectra from the Quasar RI 2000 for a good bond (black line, 0% contamination) and for a kissing bond (30% contamination, red line).

Conclusion: Kissing bond samples have been successfully manufactured which satisfy all the criteria. The protocol established is reliable and stable. Other promising avenues have been investigated. It appears that very realistic disbonds can be created by altering the diffusion bonding process of titanium plates. Moreover the ElectRelease epoxy can also good satisfactory results for quick checks.

The produced kissing bond have been used to assess the capabilities of broad band URS to detect weak adhesions between bonded metal plates. Results are promising, and in line with previous results. Shear wave resonances are affected when the bond is weak.

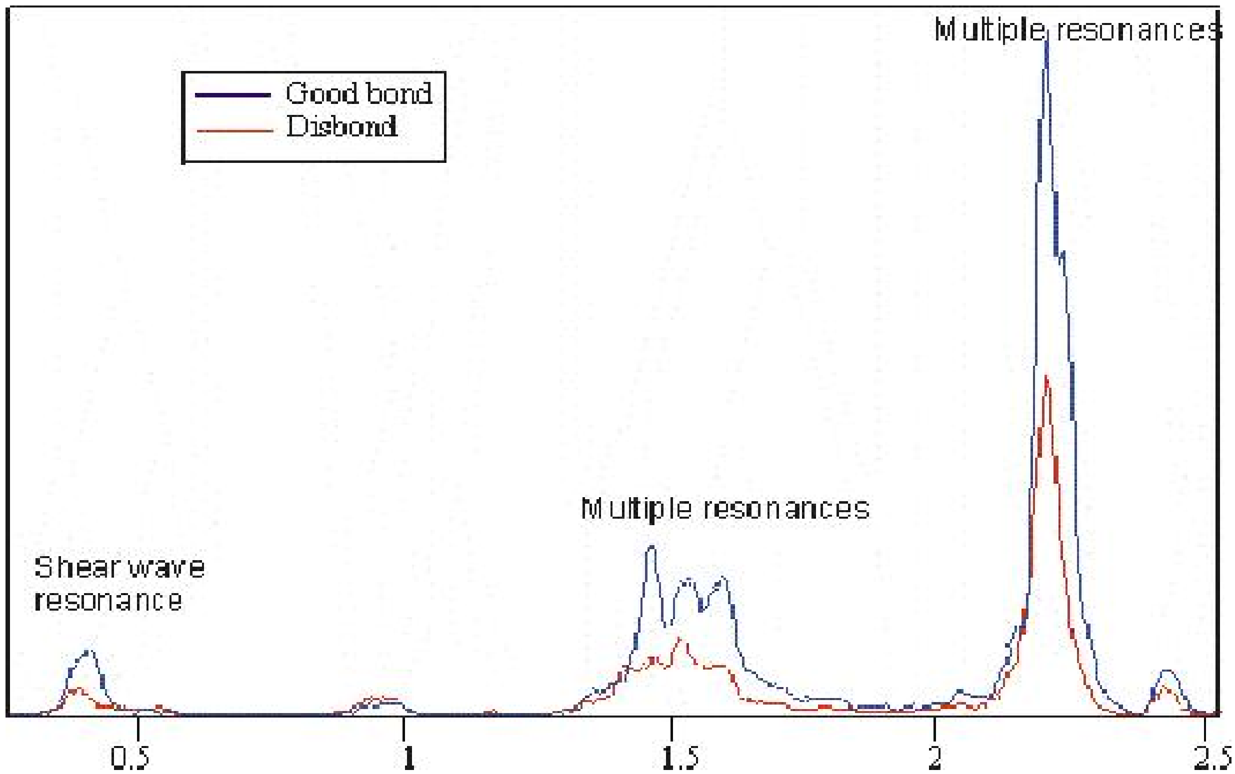

Figure 5: Spectra from the Quasar RI 2000 recorded on two positions over the titanium diffusion bond sample showed on figure 3. The blue line represents the spectrum over a well-bonded area of the diffusion bond (good bond, blue line) and the red line (disbond) shows the spectrum recorded over the region where the alpha case layer is located.

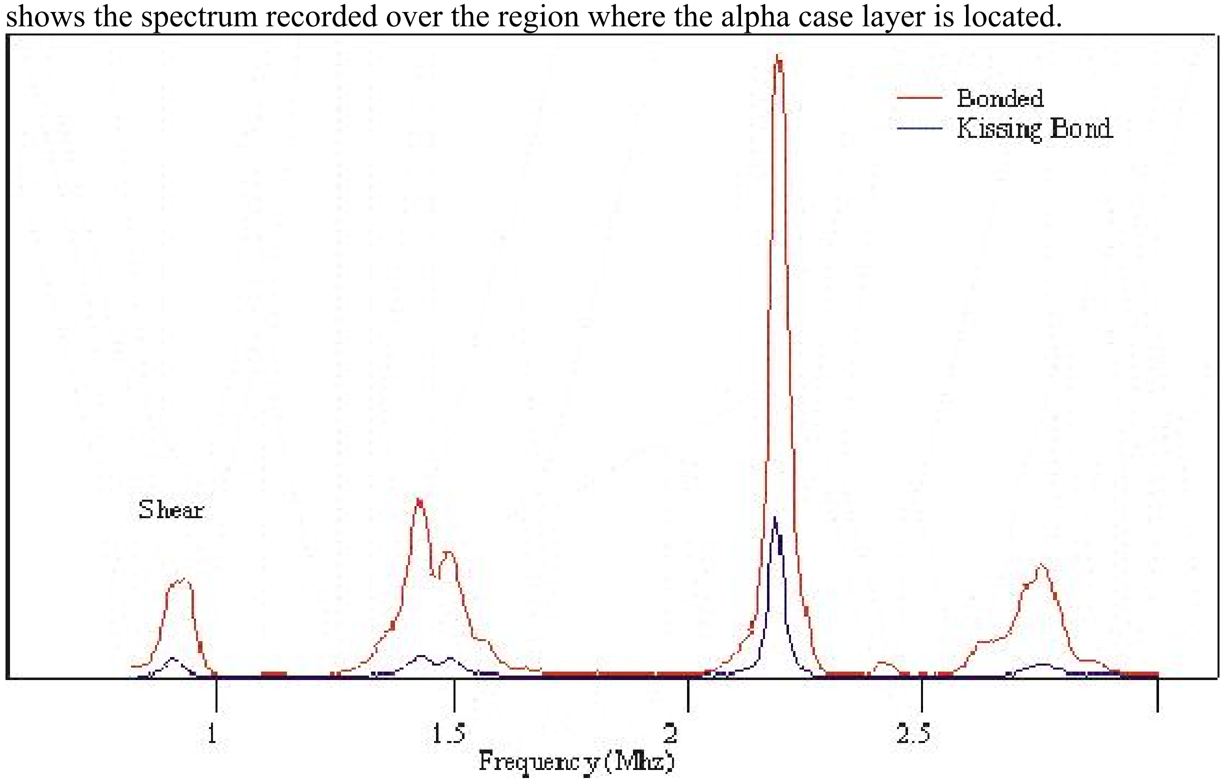

Figure 6: Spectra from the Quasar RI 2000. The red line refer to an ElectRelease bond prior to applying the electric field, and the blue line represent the spectrum after the electric field has been applied

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