Acoustic Emission Monitoring of Cold Forming Automated Operation on Airplane Wing Panels

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Abstract. Acoustic emission technology has been used in order to characterize the different steps of cold forming of Falcon wing panels. The final aim was to make a quantitative comparison between several shaping methods used: beginning with the traditional single shot manual hydraulic press, then moving to multiple shot with manually controlled machine, then in fine, to characterize the efficiency of the new automated line of forming (LFA) specially developed by and for Dassault Seclin manufacturing plant. Preliminary experiments on small panels have been conducted to define an appropriate procedure, to choose and adapt AE instrumentation and appropriate signal processing. The quantification of the AE released energy during forming allows us to confirm that the amount of local plastic strain is reduced with the new one shot automated procedure compared to the other manual qualified methods for a defined final shape.

The AE results of the monitoring of the first several panels are real time analysed and interpreted to give genuine information used for automated forming cycle optimization. We have studied the influence of cold forming parameters on AE energy release regards to the dimensional measurements. The instrumentation was initially set up directly on the panels, but considering the good results we move forward, studied and finalized an instrumentation of the automated press itself to make the acquisition data also fully automatic. The reproducibility of energy released during forming process has been verified without reducing the production rate.

Using AE sensor directly on the automated press tools, we are able to detect more process information, that is why pattern recognition analysis was applied with Noesis to characterize and identify several AE sources as fretting, tool shocks, that can induce state of surface imperfections. Cold forming cycles are performed on panel with artificial defects to verify the ability of the AE embedded system to detect crack initiation or propagation. Acoustic emission monitoring has been pushed forward as a very flexible and powerful non-destructive tool for forming operation improvement and development in the new automated forming production line, then recognized as a mean of production control.

Keywords. Acoustic Emission testing, cold forming, automated cold forming monitoring, airplane.

1. Introduction

The Falcon 7X (figure 1) is a trijet with a substantial flight range. With the capacity to reach a maximum speed of Mach 0.9 and a range of 5,950 nm (11,000 km), the aircraft is equipped with a new aero-elastic wing design whose aerodynamic performance has improved by 30%. The Falcon 7X is the world's first business jet to be equipped with a fully digital flight control system. The aircraft also benefits from low operating and maintenance costs. The first Falcon 7X flight took place on May 5, 2005. The wings panels are produced in Seclin manufacturing plant beginning with high speed machining before cold working process to give the final shape. The main policy is to improve the increase the manufacturing process with the skill to be more cleanly and more efficiently, by means of automated integrated production channels. The processes used include welding; cold forming of wing panels in a single run rather than 30, thanks in particular to greater precision of the presses; and finishing that uses shot peening with the projection of steel pellets to replace human panel beating, which can cause repetitive stress injuries.

Figure 1. Falcon 7x in flight.

To achieve this goal Dassault has specially developed a new automated line of forming (LFA). The qualification of this new method of forming imposed to make a quantitative comparison between traditional shaping methods and the new automated line of forming.

The aim of this work is to prove that the new forming method gives also better results in term of residual stresses, reducing the risk of promoting or propagating a potential defect.

2. Manufacturing a wing panel

On the opposite of Airbus design where stiffeners are mechanical fixed on the internal side of the plate, the falcon wings panels are machined including all stiffeners.

2.1 Evolution of the forming process

The original production was done manually with pressing machine and hand hammer. For example, 171 press shots are needed to give the final shape of the panel roots (figure 2).

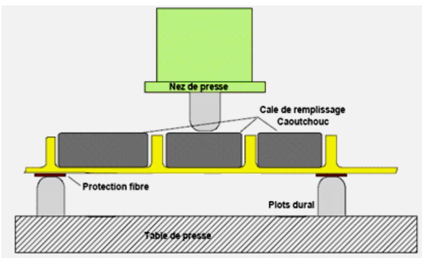

Figure 2: Example of “manual” cold forming with single punch press.

In order to increase the production rate and reduce the local strain, multiple punch tools have been developed, reducing the number of punch press operations to 12 shots (figure 3).

Figure 3: Example of “manual” multiple punches shot cold forming.

2.2 Description of the LFA

The next step was the development of a new tool, the automated line of forming (LFA), which provides the final shape of the panel in only one operation. The LFA is constituted of 6 computer-controlled modules, 3 100 tons and 3 200 tons hydraulic pressing modules. The set of punch press can be adjusted to different shapes.

The final shape can be obtained by several tools, but to qualify the process, it had to be demonstrated that the forming with LFA induce less local strain and less risk of concentration of residual stress.

Even if dye penetrant inspection is done before and after forming, it should be also proved that the process will not initiate cracks.

Furthermore, the forming process also had to be optimized and the repeatability had to be evaluated without very expensive series of tests. The sample should be a full size machined panel.

Figure 4. View of the automated line of forming.

Figure 5. View of the panel just before cold forming.

We have chosen to apply Acoustic Emission to monitor cold forming because this technique can be applied *in situ* directly in the press during the forming process [1, 2, 3]. AE is able to detect local micro strain, crack propagation and give information on the position of the events (localization). This real time technique should allow us to study the reproducibility of the LFA cycles.

3. Principe of the measurement

Acoustic Emission (AE) is the result of sudden energy release within a material, which appears as elastic wave. This technique is widely used as a non-destructive testing technique for fitness for service evaluation in industrial field [4]. AE is also a powerful tool to characterise and understand damage initiation and propagation. Most of all microscopic mechanisms has been studied and correlated with AE signals.

Many developments in AE technology, mainly developments in AE instrumentation, have occurred in the past ten years. Analytical calculations, in some cases, result in the combination of theoretical solutions with signal analysis. However, this technique is mainly experimental and the best tool for signal analysis is still source recognition and database files combined with location.

That is why tools based on signal pattern recognition have been used to allow complex problem analysis (multi-source and different propagation patterns). A multi-parametric analysis using pattern recognition and neural network via Noesis software was performed to isolate signals such as fretting noise [2], mechanical noise from press and define a real-time analysis based on AE features [3, 4]. Nevertheless, in order to feed the database for pattern recognition analysis, different experimental measurements have been made on samples and small structures.

4. Instrumentation of the panel during forming

The use of AE in industrial environment implies to carefully study the influence of the measure on the test itself and the interaction of the forming process with the structure [5,7].

The main goal for AE technicians is to achieve good sensor coupling and mounting and check the resulting channel performance. The coupling should be effective during and after all the manipulations of the panels to guaranty reproducible results.

Preliminary experiments have been conducted to define an appropriate procedure, to choose and adapt AE instrumentation and appropriate signal processing to eliminate as much mechanical noise as possible, and at least recognise to post eliminate by post processing. For panel instrumentation sensors are maintained with duct tape and coupling is made with mechanical grease qualified in term of pollution and corrosion by Dassault Seclin production.

As the panel had to be manipulated by hand, the weight (panel is very flexible) of the instrumentation has to be minimized and the size should be compatible with the effective space available in the press tool. For all these reasons, R50 sensors and IL40 preamplifiers have been chosen (Figure 6).

Figure 6. In-line miniature preamplifier (8.26cm x 2.87cm x 2.22cm, 54 grams) and R50a sensor (19 x 20 mm, 32 grams).

Cables are secured with duct tape and connected after handling and installation into the LFA (figures 7 and 8).

The coupling of the sensor has been verified by Hsu Nielsen source and location simulations before the introduction in LFA.

During these preliminary experiments, in parallel with the Hsu Nielsen source, we used the AST function (Auto Sensor test) to send calibrated pulse on each sensor. Neighbor sensors receive the transmitted elastic waves thus allowing the verification of the good transmission on well coupled sensors. Furthermore, AST function was used before and after forming to check that no loose of sensitivity takes place after the shape modification (curvature).

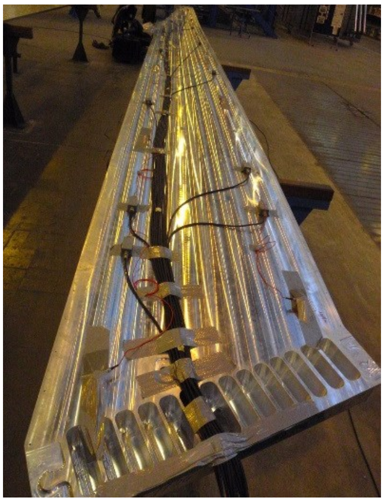

Figure 7. View of an instrumented panel (internal face).

Figure 8. Installation of an instrumented panel in the LFA.

5. Result of the cold forming of first Panels

The cold forming process does not give too much AE hits. Each step of straining gives rise to detectable AE with very few parasitic noises. After real time filtering we can observe the cumulative curve given in figure 9 graph1. No loss of sensitivity is observed after pressing.

Measurements of the energy delivered by the 6 loading modules are given with the same scale of time in figure 9 graph 2. AE begins slowly with the first step of press cycle, and then becomes regular with loading steps. The load is applied by steps, but the press unloads very quickly. At the unloading, a big peek of Acoustic Emission is detected. The pattern recognition analysis was performed and does not give any population that can be attributed to mechanical noise or fretting. Considering experience of local works and experts, it was known that during manual forming of complex pieces, a progressive unload was better. Then it has been decided to reduce the speed of unload of the LFA. Results are given in figure 10.

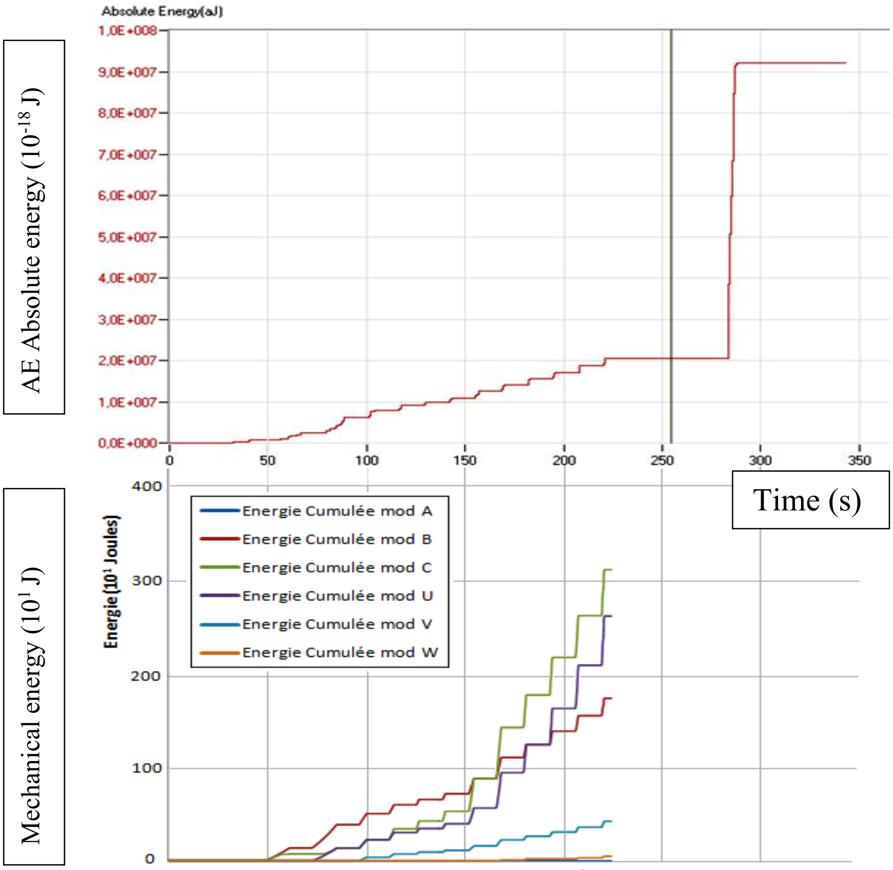

Figure 9. First results of LFA

Graph 1: Cumulative AE energy versus time
Graph 2: Energy release given by load and displacement transducer of LFA.

For the second panel the loading speed and the unloading speed is the same. No AE was detecting during unloading. The suggested explanation is that as the panel is not homogeneous in terms of thickness and stiffness, there are some areas (maybe thinner) which undergo plastic strain as more resistant areas are releasing their elastic strain.

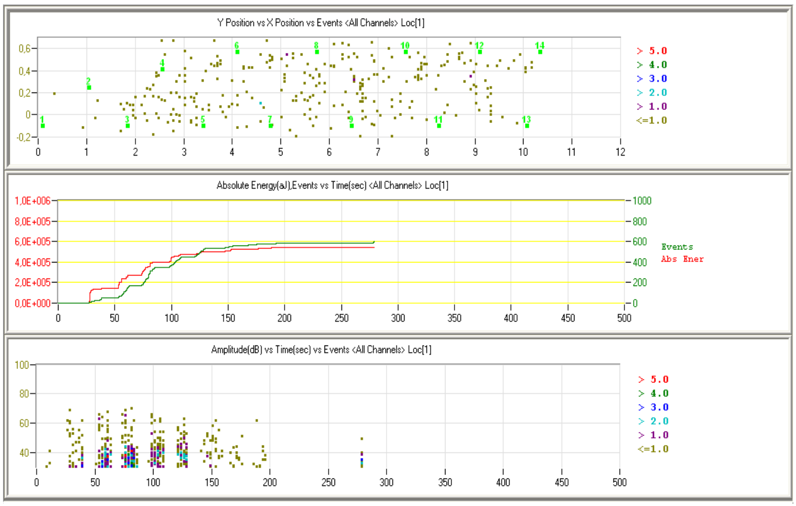

Figure 10. Results of second panel.

Graph 1: position of the event localized on the panel
Graph 2: AE cumulative energy (red) and cumulative event vs time
Graph 3: amplitude of the event versus time.

Figure 10 is also presenting the location of AE events, showing that there is no concentration of events. The moderate amplitude of the events does not indicate any crack propagation, only plastic deformation.

Six panels have been tested with AE monitoring. Even if the panel cycle is a little bit different, without the optimized unloading speed, AE is very homogeneous for the 6 panels and is reduced by at least 3 compared to the same panel made with manual punch press.

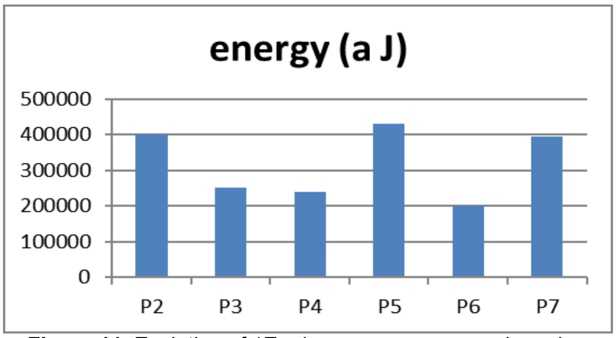

Figure 11. Evolution of 1E release energy vs panel number

6. Signal processing

Since we multiply the configuration of test with several panel reference and shape, we get different configuration of the LFA tools. Then we get some more difficult tests and we have to apply pattern recognition analysis (Noesis) in order to filter out some noises. Figure 12 shows the principal component analysis of non-genuine signals which has been recognised and filter out after test.

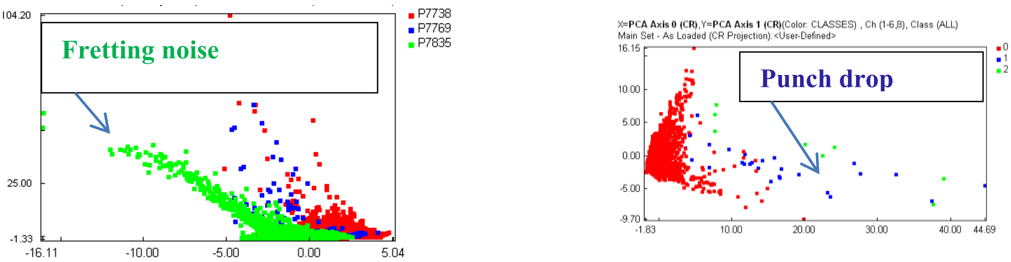

Figure 12. PCA projection showing the difference between genuine EA (red) and fretting noise (green) and mechanical shocks (blue).

7. Instrumentation of the LFA

The test of the panel is quiet easy to perform, but it takes half a day to set 20 sensors on the panel. That is why we fixed four sensors on the support of the panel inside the LFA. After a rapid study of wave propagation we measure that an attenuation of 12 dB can be measure between sensors in the panel and sensors in the LFA. Figure 13 show the sensors on the supports in the LFA.

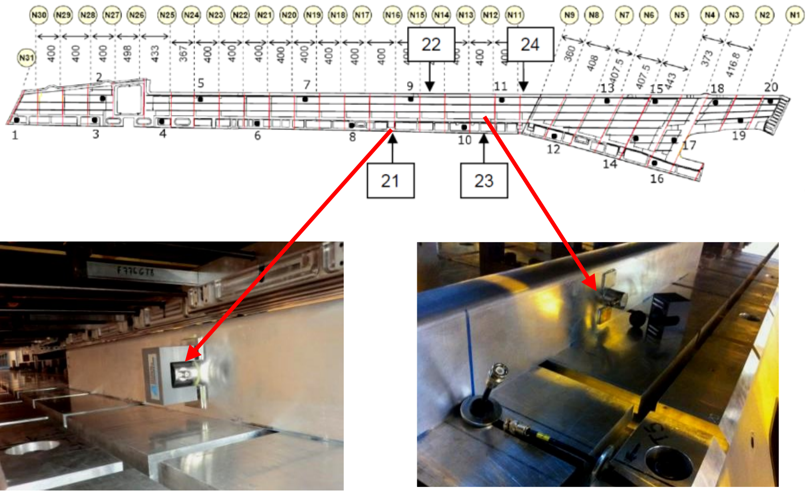

Figure 13: position of the 4 sensors fixed on the LFA support compared with the sensor layout on the panel.

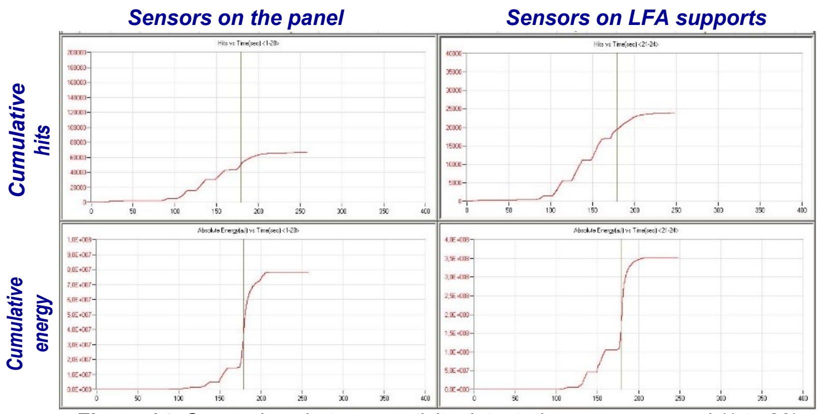

Figure 14. Comparison between activity detected sensors on panel (1 to 20) and activity detected by the sensors fixed on LFA (21 to 25).

The comparison between activity detected by sensors on the panel and those fixed on the LFA is very good. Only the level is different, but the result can be exploited to monitor the production process (figure 14). The AST done at the end of the test show that even if the sensors are not directly set on the panel the transmission between panel and sensors on the LFA is still efficient at the end of the cycle.

As the LFA is equipped, it is very easy to build a data base and use it as a quality control tool. The acoustic emission test does not introduce additional time and the final curves are available at the end of the forming cycle. Figure 15 shows the reproducibility of the measurement on several panels.

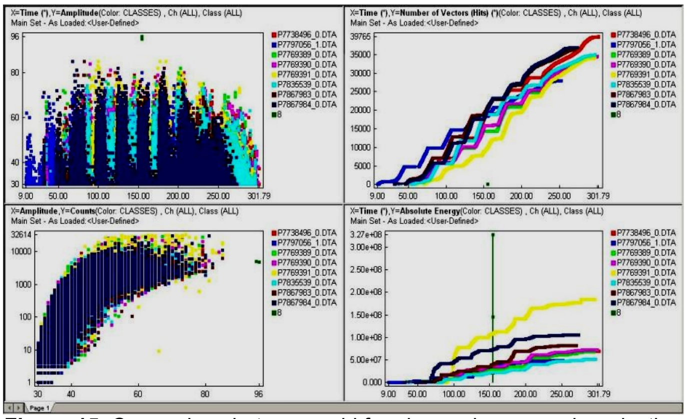

Figure 15. Comparison between cold forming cycle on panel production

8. Test on artificial "defect".

As Seclin workshop has kept a non-conform panel, it was a good opportunity to perform some artificial "defect". 3 types of "defect" have been introduced on the same panel before cold working. Figure 16 shows the size and the global morphology a notch made by sawing, a scratch made by a cutter knife and a small notch made with an electric pencil.

Figure 17 shows the energy distribution versus channel during the cold forming. All artificial "defects" give an increase of the local release AE energy. After forming, visual inspection gives no evidence of propagation of these artificial "defect". Nevertheless, AE gives significant increase of energy compare to area were no "defect" were introduced.

This experiment is not representative of real crack propagation during forming, but gives evidence that local unexpected plastic strain can be easily detected

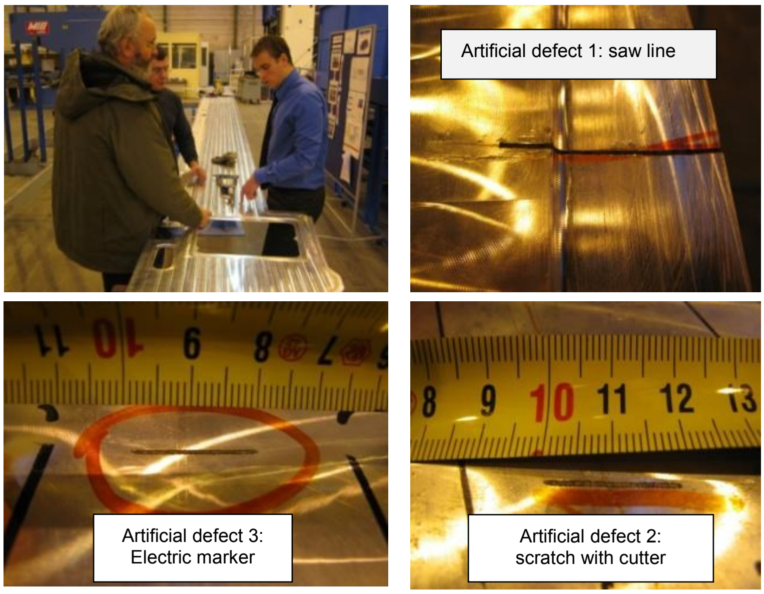

Figure 16. View of "artificial" defects made on a panel out of service

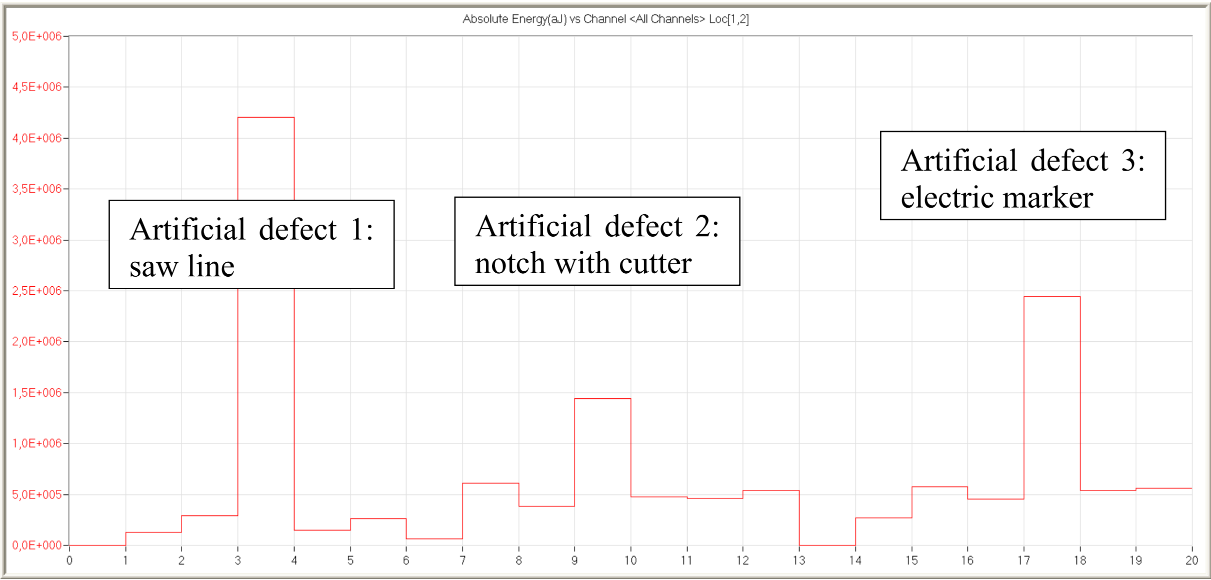

Figure 17. Cumulative energy versus channel on panel with "artificial" defects"

9. Test on experimental welded panel.

Panel are machined in a single plate for normal production. An experimental panel has been assembled with two welds.

Some preliminary tests has been conduct on samples to characterized the emissivity of a weld under 3 points bending test. The emissivity of a welded sample is much greater than a seamless sample and furthermore increasing when a defect is present in the welding seam. When the tempered heat treatment is done under stress we can monitor the stress release inside the weld (figure 18).

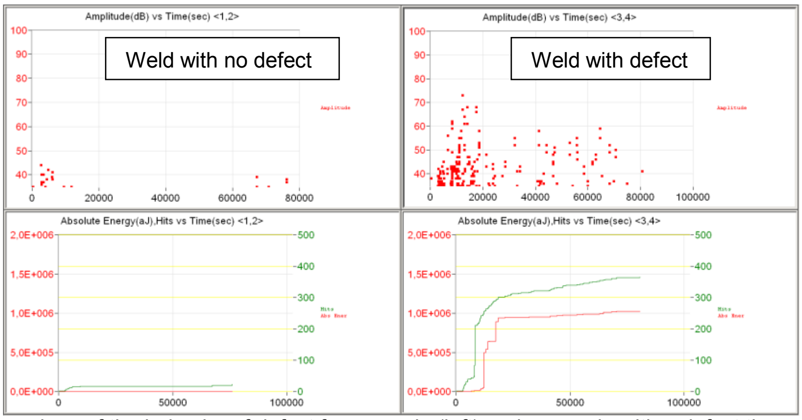

Figure 18. Comparison of the behavior of defect free sample (left) and a sample with a defect the weld seam (right) during tempered heat treatment à 170°C.

Graph1: amplitude versus time
Graph 2: cumulative energy and hits versus time

As we demonstrate the monitoring of the heat treatment can be done me move toward a large scale panel.

During the stage of cold forming of welded panel some minor sources are located near a hole in the area of sensor 13, but significant source is detected in the welds area. After forming the panel is maintain under stress by a metallic casing and introduce to a furnace for heat treatment.

Sensors have been let on the panel in order to follow the stress relaxation during tempered heat treatment at 170°C. Sensors are connected to preamplifier outside of the furnace (Figure 19).

 

Figure 19. Position of the panel in metallic casing and view of sensors (left) and preamplifiers outside the furnace (right)

No significant acoustic emission is located at the welded areas. The only sources we can observe are situated at the junctions of the parts of the metallic casing.

10. Conclusions

This study has been conduct over several months in order to help to optimize the cold forming of panel in the new automated line of forming. The first cycle of forming is indicating that le speed of unload was too high, the subsequent cycle with adapted speed give us the confirmation of a benefic effect of releasing the load progressively.

The direct comparison between the Acoustic emission behavior of manual cold forming and the AE emissivity of LFA has been done. It gives us evidence that the level of stress is reduced with the LFA process in term of AE energy release and AE concentration. The LFA process induced a more scatter internal strain compare to the manual process which produce more local high stresses.

With the AE instrumentation of the LFA itself, the reproducibility of the cold forming cycle has been verified.

AE as also used as a significant support of the development test including a new assembly process with welded panels.

AE monitoring of such key production tools gives decisive information for process management and quality control

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