CERAMIC SHOT
EXPERIMENTAL DEMONSTRATION OF INTELLIGENT PEEN FORMING ON ALUMINIUM ALLOY

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ABSTRACT

Today, peen forming is performed through a step by step peening operation with partial coverage and partial automation. It requires time, experience, controls and correction operations. There is definitely a need for automatic manufacturing of large shaped components such as: wing skin, spar, wing panels… By coupling the existing knowledge of experts, numerical results, and experimental data, with special automatic learning and optimization techniques, CADLM thanks to its Advanced Intelligent Design of Structures System can provides a solution for a fully automatic peen forming process where instructions given to the robot would directly lead to the final required shape.

The paper first reports experimental works with ceramic beads on material to built a data base of elementary cases to allow capitalising results and generating rules. Different parameters have been studied such as bead size and velocity and panel thickness.

Then reverse problem has been studied: bigger flat panels of 2017A T4 aluminium alloy were peened under various conditions. Curvature was measured in different locations to describe the panel shape. Experimental results on flat panels compared with predicted curvature are presented. Very good correlation has been found. Roughness measurements show that it is possible to combine high distorted shape with good surface condition without any further finishing operation. Application on actual parts with thickness variations and pre-bended shapes would be necessary to validate the process.

KEY WORDS:

Aluminium, automatic peen forming, CAD, calculation, ceramic shot, shape, prediction, roughness, saturation.

METHODS

2D roughness measurements were conducted with MAHR perthometer M3 equipment.

Almen intensity and arc height were measured in accordance with NF L 06-832.

Shape control with gage device (picture 1) and peening operations in an automatic direct pressure cabinet have been carried out at SEPR Demonstration Facility in France.

INTRODUCTION

Shot-peen forming process is ideal for developing curvature to shape thin large panels. It’s possible to achieve a wide range of curvatures by adjusting peening parameters such as Almen intensity and coverage rate.
The automation of peen forming is of great interest: If one can forecast final component shape and roughness according to material characteristics, original and final shape (from CAD data) and peening parameters on each local area, then one can get the shape by direct saturated peening process with aerodynamics compatible roughness and 100% automated peen forming process.

PRINCIPLE OF "AIDS" SYSTEM

CADLM has developed "AIDS" (Advanced Intelligent Design of Systems) an intelligent optimal design system where current best knowledge of the experts is intelligently mixed to the results of real experiment returns.

To develop this system, it is required to build a database of examples with all parameters related to the process and that can describe it. We can identify:

- Primitive descriptors such as shot characteristics, target properties, peening parameters, …
- Intelligent descriptors that summarize the current knowledge related to the process such as analytical models, scientific theories…

Then, by means of an automatic learning tool, rules are generated from this database to simulate results, i.e. setting of all input parameters. In the metal forming case, this step allows to predict the shape of the metal part starting from the applied peening parameters.
By applying reverse problem, it is possible to define the shot-peening parameters to apply in order to generate the desired shape i.e. from the plastic strain field in the component.

EXPERIMENTAL MEASUREMENTS FOR DATABASE CONSTRUCTION

The database was built from various experiments with ceramic shot on 2017 A T4 aluminium alloy parts.
In a direct pressure cabinet, Almen intensity and arc height on aluminium strips of different thicknesses were measured for different peening parameters:

- Ceramic shot sizes : Zirshot® Z210 (210-300µm)
  Zirshot® Z425 (425-600µm)
  Zirshot® Z600 (600-850µm)
- Air pressures : from 0.5 bars to 5 bars

The Almen intensity measurement was performed in accordance to NF L 06-832 on standard Almen strips 76.2mm x 18.9mm with high precision Almen gage.
A wide range of Almen intensities was obtained, as shown in fig. 1.

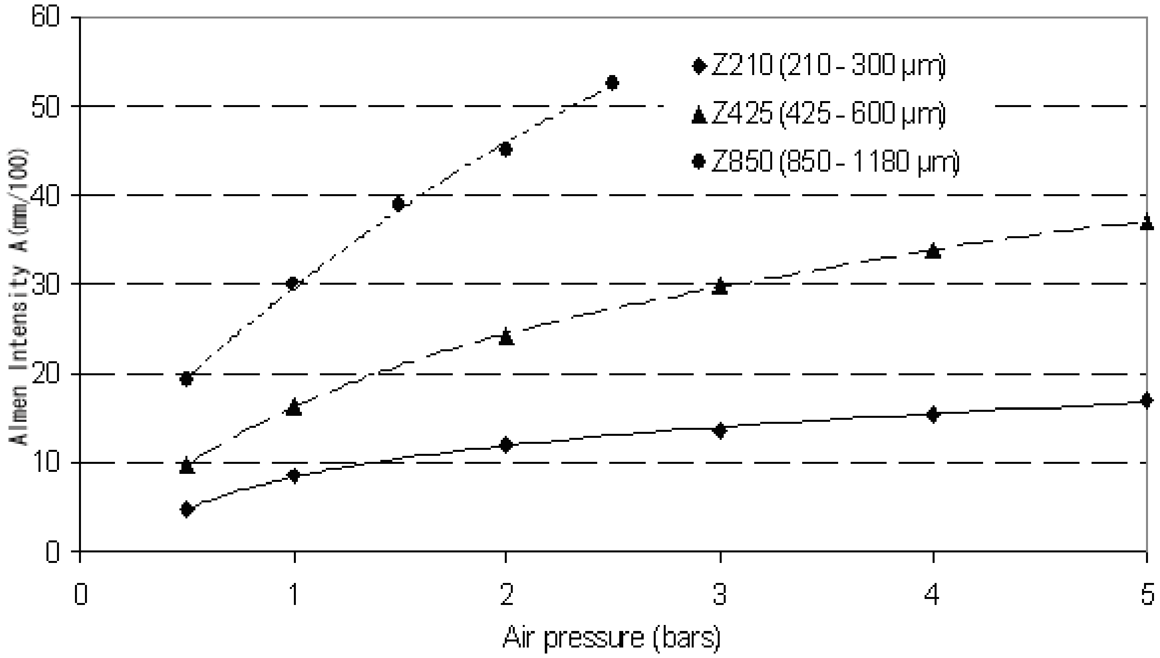

Fig. 1: Almen intensity for several peening conditions

Then laser cut strips (76mm x 19mm) of 2017A T4 aluminium alloy were peened and the arc height at saturation has been measured with the Almen gage. Saturation was defined as for Amen saturation curve i.e. the first time t such that at time 2t the arc height variation is equal to or less than 10% of the arc height at time t.

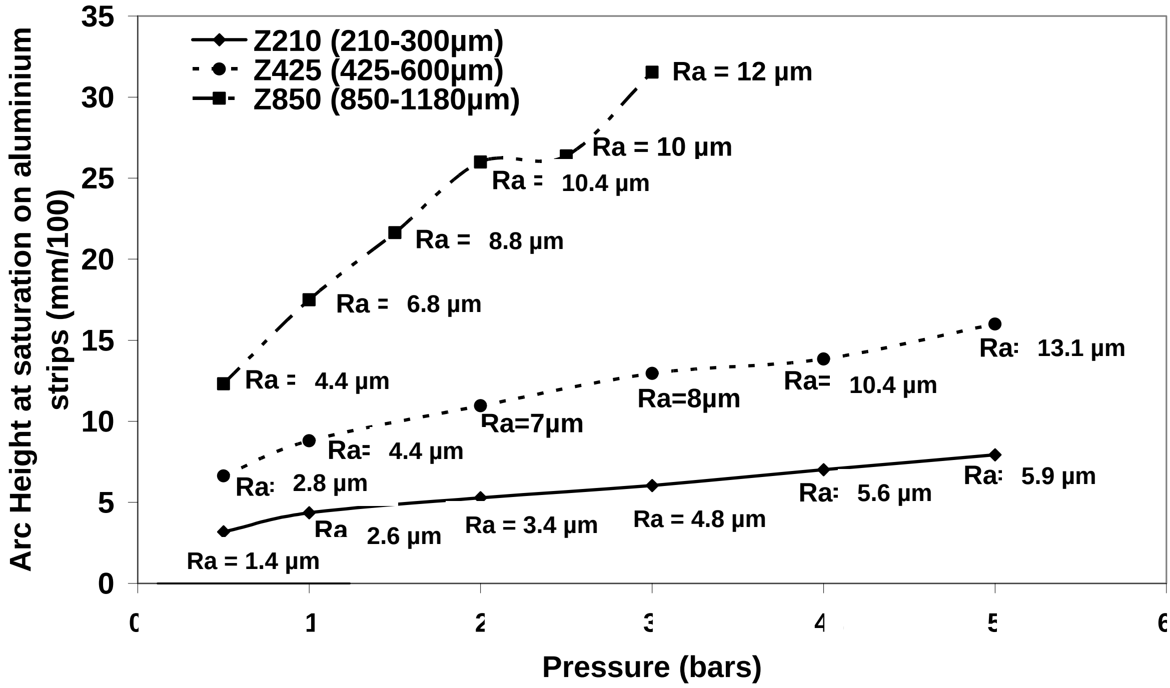

Fig. 2: Curvatures obtained on 3 mm thick aluminium 2017A T4 strips (76mm x 19mm) and measured roughness

By selecting the proper media size and the adequate peening conditions, it is possible to achieve high curvature with good surface condition.
Those results were introduced in the shot-forming system to enrich the database.

FORMING OF ALUMINIUM PLATE AND COMPARISON OF MEASURED AND PREDICTED CURVATURE

Flat panels (250 x 500 mm – different thicknesses: 3 and 5 mm) of aluminium alloy were divided in 6 areas and peened independently, with given parameters, changing Zirshot® size, and nozzle air pressure. Final distortions and roughness were measured. To characterize the final distortion, the flat panel was meshed and the height of several points has been measured. The flat panel is divided as shown in figure 3 where:

- Z1 to Z6 represent the area No 1 to No 6 corresponding to 6 sets of parameters
- C1 to C6 represent the center of each area where distortion has been measured
- P1 to P12 represent the corner points of each area where distortion was measured

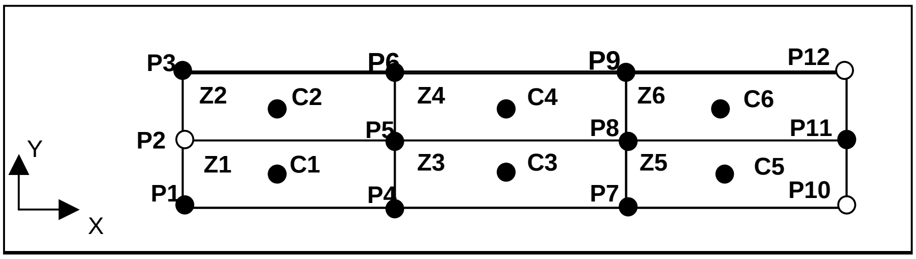

Fig. 3: Map of panel division. White points (P2, P10, P12) are reference points.

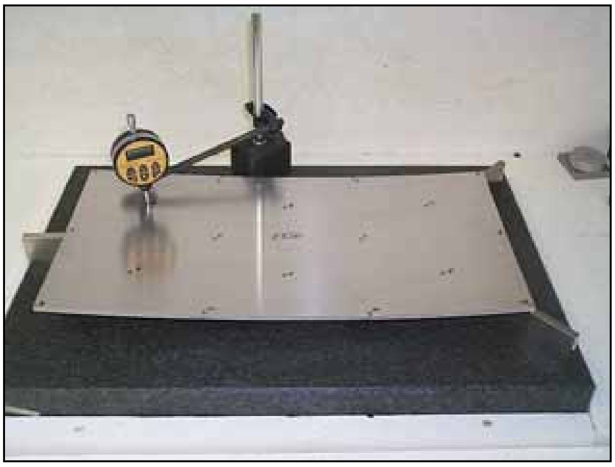

Fig. 4: Method for curvature measurement

Fig 5: Peening Operation

The following table gives experimental results obtained on 5 mm thick panels peened with Z850 in different conditions and the results obtained from the shot forming simulation software. A very good correlation is clearly shown between measurement and simulation. This means that it is possible to predict the panel shape with a very good accuracy.
Virtual shape can be observed with the software display (Fig. 6) to follow the successive steps of the shape forming process.

Table 1: Comparison between measured curvature and prediction with SHOT FORMING tool on 5 mm thick aluminium panel

Point location on the map	**Distortion (mm)**		**Error (measured value – simulated value) (mm)**	**Error (%)**
	Measured	**Simulated**		
P1	2.56	2.81	-0.25	9
P2	**0**	**0**	**0**	**0**
P3	2.56	2.63	-0.07	3
P4	-8.04	-8.10	0.06	1
P5	-10.24	-10.11	-0.13	1
P6	-7.31	-7.41	0.1	1
P7	-9.30	-9.52	0.22	2
P8	-11.91	-11.74	-0.17	1
P9	-8.70	-8.91	0.21	2
P10	**0**	**0**	**0**	**0**
P11	-3.23	-3.38	0.15	4
P12	**0**	**0**	**0**	**0**
C1	-6.03	-5.89	-0.14	2
C2	-5.2	-5.04	0.69	3
C3	-11.72	-11.73	0.01	0
C4	-11.1	-11.1	0	0
C5	-8.67	-8.58	-0.09	1
C6	-8.07	-7.98	-0.09	1

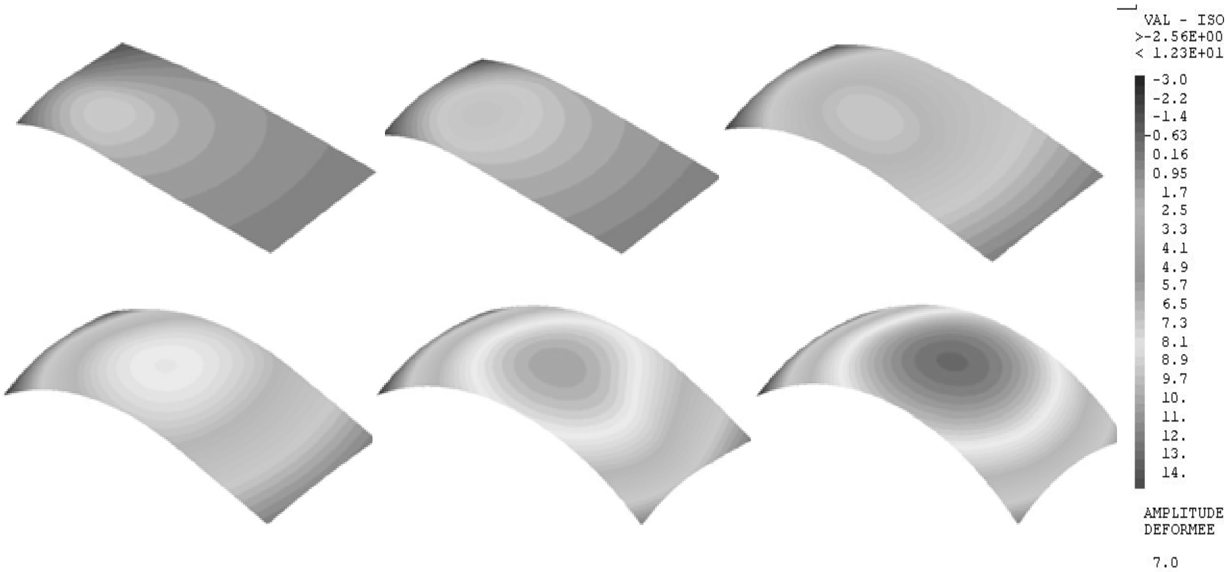

Fig. 6: Simulated successive panel shapes after each of the 6 peening steps.

The roughness of this shaped panel is between Ra = 4 µm and Ra = 12.9 µm depending on the peening parameters at the considered area.

By applying a 2^{nd} peening under low pressure at 0.5 bars, it is possible to uniformly smooth the surface and achieve lower roughness without consecutive curvature change. In the case here presented, final Ra was around 7 µm (max. value/2).

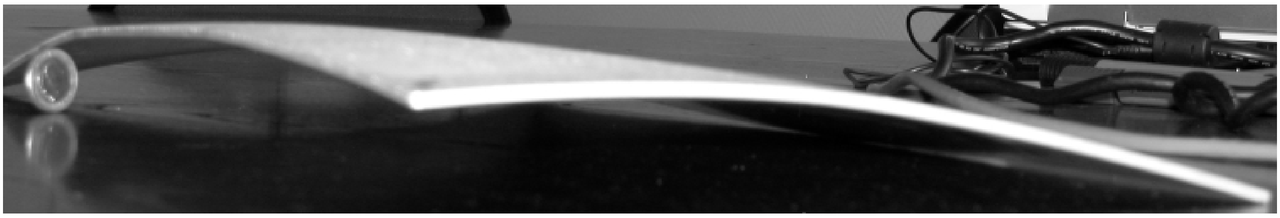

Fig. 7: Aluminium panel after shaping by peen forming (note the1€ coin as size ref).

SHOT-FORMING SOFTWARE

Developed by CADLM, this software, directly interfaced with major CAD and FEM systems, allows aircraft panels manufacturers to shape large panels using shot peening process.

This can be helpful at different process levels:

- Machine calibration for a constant quality
- Direct virtual forming: after original panel shape input, imported from CAD or FEM files and defining the peening parameters, forecasting the simulated shape of the final panel.
- Automatic forming: After original and desired final panel shape files input (as imported CAD or FEM files), Shot-forming will automatically give all the commands to the machine robots that will enable to reach directly the final shape (shot peening processing parameters in each specific panel area) without any iteration, without any intermediate measurement and without any additional decontamination neither finishing operation.

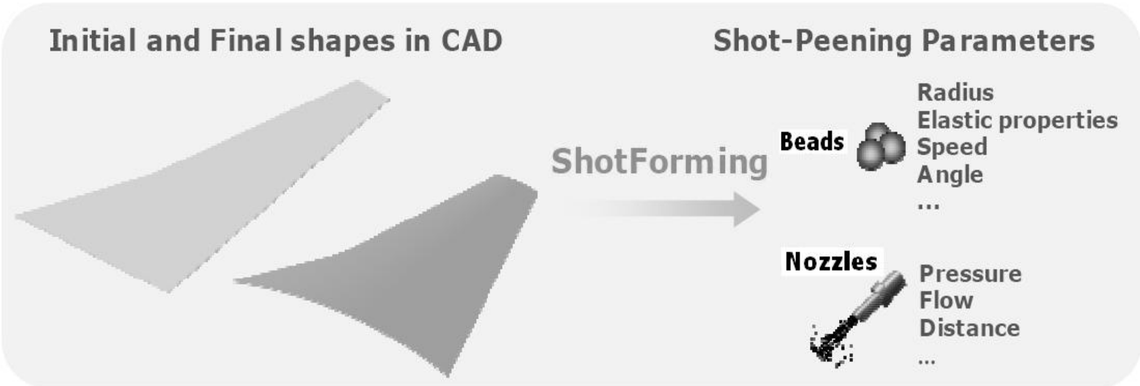

Fig. 8: Flow image of Shot Forming.

CONCLUSION

Thanks to ceramic shot, it is possible to obtain significant curvature together with good surface conditions without any further finishing operation such as decontamination or surface finishing.

At pre industrial demonstration scale, a very good correlation was found between measured and predicted curvature with shot-forming tool.

To go further, it is now necessary to validate the shot-forming system with ceramic shot using industrial equipment, on larger and complex panels, with automatic system.

ACKNOWLEDGMENT

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