A NEW USE OF COMPOSITE MATERIALS FOR FAN DEEP-DRAWING MATRIXES

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Abstract. *The necessity of adapting the standardized fan models to conditions of higher temperature has emerged due to the growth of concern referring to the consequences of the gas expelling after the Mont Blanc tunnel accident in Italy and France, where even though, with 100 fans in operation, 41 people died. However, since then, the defied The bigger cost of a deep-drawing process is known as the manufacturing of matrixes in steel. Due to that, for prototype confections, where the final shape of the good is not completely known, this process can lead to high cost. This work provides an alternative to the common used matrixes by a new technology to manufacture matrixes for deep-drawing fan blade prototypes. This technology presents its innovation by using punches and dies made by composite materials, with high rigidity and compression resistance. It is shown experimentally, that the composite matrixes could comply with the forming requirements. Moreover, they can be reworked easily in case of design changes and corrections and needs less investment, which makes them ideal for prototypes.*

Keywords*: Aerodynamic profiles, Fan blades, Deep-drawing, Composite Materials, Sheet metal forming*

1. INTRODUCTION

In order to reduce the costs in a development design of a deep-drawing matrix, this work describes an alternative matrix made by composite materials specially reinforced against compression forces to provide the rigidity for a deep-drawing process of a fan blade. The blade design is composed by two deep-drawn shells as panels joined by welding. Thus, it was used stainless steel AISI 409 plates with 2 mm thickness to be formed as aerodynamic profiles (pressure and vacuum side). The developed matrix objectives to verify its technical viability.

2. PUNCH, BLANK-HOLDER AND BASE DESIGN

For conforming the aerodynamic profiles of blade shells, a matrix was made by a blade model. This model gave the base shape, the blank-holder location and the punch shape. As a general sense, deep-drawing matrixes are made of steel, in order to comply with the stresses during compression and provide repeativity, looking for a serial deep-drawn production. But, due to elevated investment cost in a development design, it was chosen do build a composite matrix with some reinforcements for the application.

Table 1. Matrix Materials, Foroni (2004).

item	Material	Punch	Blank-holder	Base	
01	ARALDITE SW 419	2,0	1,0	3,5	kg
02	RESIN LY1316	16	13	30	kg
03	HARDENER HY1208	1,6	1,3	3,0	kg
04	QUARTZ	156	130	286	kg
05	GLASS FIBER FABRIC TLS 160-90	0,15	0,10	0,15	kg
06	GLASS FIBER FABRIC TLS 260-90	0,50	0,30	0.40	kg
07	CRISTAL GLASS	1	-	1	pç
08	HARDENER HY2969	8,3	6,7	15.6	kg

- Hardener HY1208 – for catalyst LY1316 and Araldite SW419 resins
- Hardener HY2969 – for adjust the catalyst rate, with HY1208.
- Quartz – industrial use sand
- Glass Fiber Fabric TLS 160-90 – Interlaced Glass Fiber at 90º with density 160g/m2
- Glass Fiber Fabric TLS 260-90 – Interlaced Glass Fiber at 90º with density 260g/m2
- Vidro – to provide flat surface on base matriz
- Calibrated Wax – to provide controlled spacing between surfaces
- Wood – to create boxes to build the matrixes

So, this matrix adopts a very rigid superficial shell to comply the drawing stress made by Araldite SW 419, Huntsman (2003), and, as different from composite matrixes, a massive matrix filled by quartz and LY 1316 resin. The materials used can be seen on Tab. 1.

2.1. Matrix Base Manufacturing

Firstly, it was build a blade model. It was generated by using of gauges with the aerodynamic profiles positioned according to design. After positioning, the gauge skeleton was filled with mass. The model accuracy with the design is obtained by the quantity of gauges used.

A second step was made a wooden box for laminating the matrix allowing the insertion of the blade model inside it. The model was centered in order to let a minimal spacing of 100mm from each side of the box. The box must have 300mm minimal height.

After positioning the model, it should be applied Araldite SW-419 in the box walls and the blade model in order to make a 1.2 mm thickness layer. For this case, as a study and due to the necessity of possible dimensional repairs, it was used 10mm thickness to allow some external layer removal as dimensional adjustment.

After post-curing the gel, three layer of glass fabric TLS160 – 90 was laminated with resin LY1316. It was used 100pp of resin LY 1316, 10 pp of hardening HY1208 and 12pp of hardening HY2969. On areas when the gel as cured it was used sandpaper 100.

Besides laminating the TLS 160-90, it was laminated five layers of TLS 260-90 with the same resin.

Later on laminating the glass fiber layers, the remaining box volume must be filled with quartz and resin. As the mix is exothermic, to avoid heating the matrix too much and losing the mechanical properties of the composite material, it was made on steps. In each step it was used 1,0kg of resin LY1316, 600 g of hardener HY 2969 and 13kg of quartz. On each step, the mix was compact and the matrix was cooled.

At the last filling up step, it was used the crystal glass to get a plain surface.

Subsequently of matrix cure, guide and attach pins was settled.

2.2. Blank-Holder Manufacturing

The blank-holder manufacturing was made by matrix base. To that, it was made a wooden box with a blade shape at the internal surface of the matrix with height 200mm to allow manufacturing the blank-holder with the same external shape of the base box and internal shape of the blade model..

To avoid clinging, it was used modeling wax between the base and the future blank-holder. After that, it was applied Araldite SW-419, laminated TLS 160-90 and TLS 260-90 filled with quartz according to the base manufacturing process.

After curing all composite materials, it was installed metallic sliding sleeves to be used with the guide pins of the base.

2.3. Punch Manufacturing

The punch manufacturing was made by the base and blank-holder. To that, it was used calibrated wax with the stainless steel plate thickness on base to allow a plate insertion and also some minimal gap between the blank-holder and punch allowing its sliding.

Figure 1: Base, punch and blank-holder. Foroni (2005).

Besides that, it was applied Araldite SW-419, laminated TLS 160-90 and TLS 260-90 filled with quartz according to the base and blank-holder manufacturing process.

Later on, finalizing the cure of all composite materials, it was used the crystal glass do generate a plain surface and it was put metallic reinforcements to distribute the stresses of the press machine for all punch-base surface. The complete matrix can be seen at Fig 1.

By developing the deep-drawing tools, the preliminary deep-drawing calculations, which give us the loads to be considered on deep-drawing and matrix manufacturing, it is allowed the making of experimental tests and product validation, as described on item 3.

3. EXPERIMENTAL TESTS

The experimental validation of the proposed blade panels can be divides according to the involved processes, besides the validation of the final product in prototype tests. To simplify the work, on this work, the prototype experimental tests, welding and high temperature material performance will be omitted, as soon as, some mechanical properties were obtained by literature.

The blade manufacturing process can be divided in two sub processes: welding and deep-drawing. On next, we will be describing only the deep-drawing process.

3.1. Deep-drawing process

Even considering the selection of stainless steel AISI 409 due to its conformability, the difficult to discover the maximum localized stresses during the blade conformation obliged to perform conformability tests. Thus, it was made real scale tests to control and discover any problems. It was considered the pressure side of the aerodynamic profile the most critical conformation, due to its drawing depth. If the pressure side conformation would be viable, the vacuum side would be viable too.

The major problems in a deep-drawing process are: wrinkles on the conformed areas, plate breaking, excessive localized estriction, number of steps for full conformation and, finally, the force needed for drawing to select a press machine. To avoid some of these problems, it was used some cares as: deep-drawing with stretching , with a pressed blank-holder to avoid wrinkles, the use of a two-millimeter plate, a slow process to avoid plate breaking and excessive localized estriction and, finally, the adoption of a pressing machine with 50% extra capacity.

3.1.1. Initial test with SAE 1020 steel

For the first test, it was considered as material the carbon steel SAE 1020 to minimize the development costs. Thus, it allowed the comparison among the tests with carbon steel and stainless steel AISI 409.

A two millimeter carbon steel plate was conformed using the maximum friction area between the blank-holder and the matrix base. So, it was performed a more conservative test considering the plate slide between the blank-holder and the base. It was also used a square mesh of 50 x50 mm to verify the most affected areas by estriction. The plate with the referred mesh prepared for deep-drawing can be seen on Fig. 2a.

At this test, it is described the steps in order to detail the entire procedure. At subsequent tests, steps were omitted, focusing mainly on tests results.

As shown on Fig.1, the matrix is not a plain surface for plate lay down. Due to that, to lower the blank-holder, some load is add to provoke an initial deformation on plate. This load is exerted by approximately 20 M12 bolts to oblige touch the entire surface of the matrix base except the punch-related area. This previous deformation can be seen at Fig. 2b.

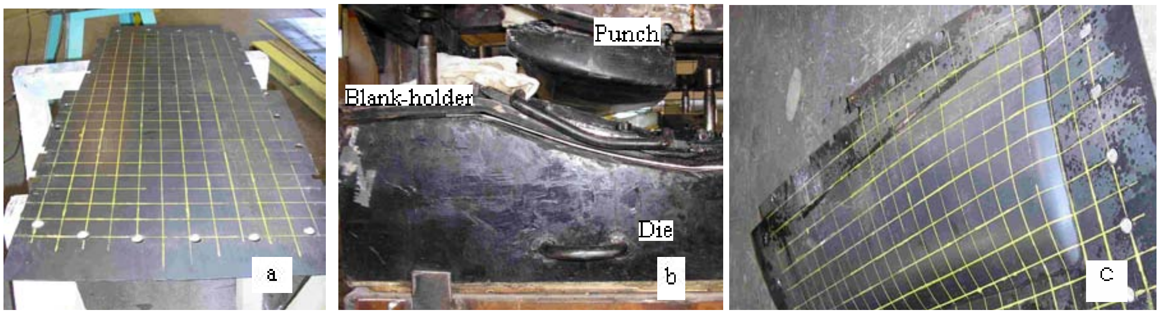


Figure 2. Conformation of Sheet 1 by blank-holder load. (a) Prepared Sheet; (b) During Process; (c)Conformed sheet Foroni (2005).

After the initial conformation by the blank-holder, it can be guaranteed the existence of a pre stress at Sheet 1. The next step is using the punch with a pressing machine.

After the initial conformation, the punch were lift up and a hole were made on sheet t verify is the conformation was complete. It was discovered the load force was not enough. However, it was already some sheet conformation.

Figure 2c indicates the conformed sheet, even at its critical region, with bigger conformation, did not present wrinkle, which shows the friction among the matrix base, sheet and blank-holder were enough to guarantee the estriction of the plate. In addition, no excessive localized deformation was noticed. This way, it was concluded that part of the contact surface blank-holder-sheet-base could be eliminated in order to facilitate the experimental preparation.

3.1.2. Load increased and lower friction

For the second test, according to the conclusions of the fist test, it was used a lower friction área, in order to facilitate the set up process, and increased the load up to the press limit, i. e., 75 tons, which is 50% higher the calculated load for stainless steel plate.

To verify if the conformation was complete, it was made a hole at the step shown on Fig. 2b which showed that the system with steel SAE 1020 could not be completely conformed even to the maximum press machine load. However, the conformation was deeper that the first test, as shown at Fig. 3.

For dimensional measure of the conformed plates, the plate was cut at the conformation edge to keep only the useful part of the final product plate. Fig. 3 shows this cut which gives us a very close view of the final shape of the blade.

Figure 3. Sheet 2 final cut for dimensional measurement. Foroni (2005).

3.1.3. Material changes

As the second test reached the press machine load limit, it was necessary to finalize the carbon steel tests. And start testing a more ductile material, stainless steel AISI 409. Thus, the 3.1.2 procedure was made with the new material. The results can be seen at Fig. 4.

Figure 4. Sheet 3 after conformation. Foroni (2005).

Figure 4 leads to some conclusions. It was used the same punch load as item 3.1.2. However, the material was fully conformed except by one bubble at the lower part of the matrix. Due to that, it was noticed that was some lubricating oil accumulation, from punch, forming a pool at that area.

Like item 3.1.2., the sheet was cut and dimensional measured.

Due to the pool formation verified, it was necessary a better control of oil leakage from the pressing machine, as much as lubricating cares, in order to avoid these interferences at system (oil pool formation).

3.1.4. Bubble Ellimination

As described at item 3.1.3, it was observed the punch loads were enough for a single-stage deep-drawing production. The pre-load made by the blank-holder avoided any wrinkles at the estriction surfaces (necking). There was no plate breaking, as soon as there was no excessive estriction. Even this, a forth test was made in order to verify and eliminate the bubble happened at item 3.1.3 and the obtaining of a final dimensional measurement of the plate according to the design. This way, a new test was performed including a hole at the bottom part of the plate to avoid oil or even air pool formation during conformation. The result can be seen at Fig. 5.

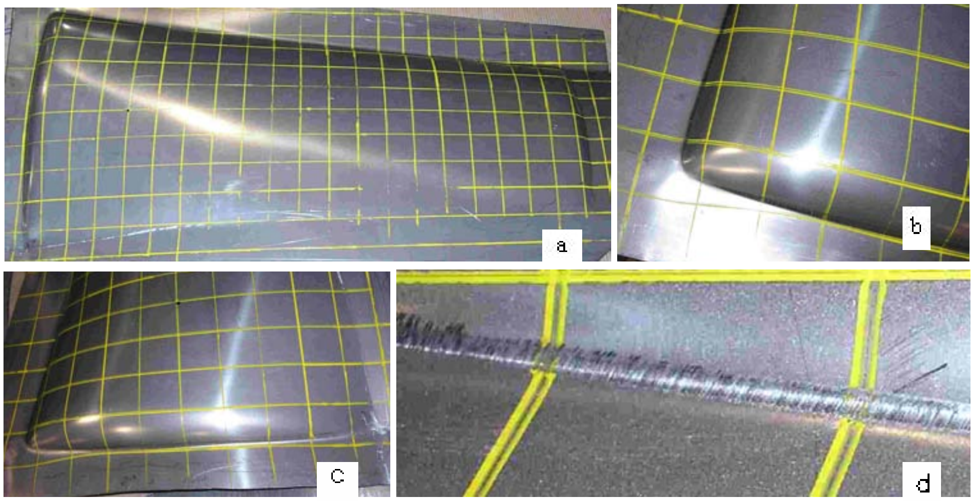


Figure 5. Sheet 4 after conformation.(a) General view; (b) Critical Section (no wrinkles); (c) Blade Root (no bubbles) and (d) Localized Estriction. Foroni (2005).

4. CONFORMED SHEET GEOMETRY ANALYSIS

On sequence, some considerations about the relation and the role of the geometric variations of blade shells in deep-drawing process parameters, which can lead to some fan efficiency losses, will be discussed. Also, some conclusions will be made about the deep-drawing process and the necessity of enhancements.

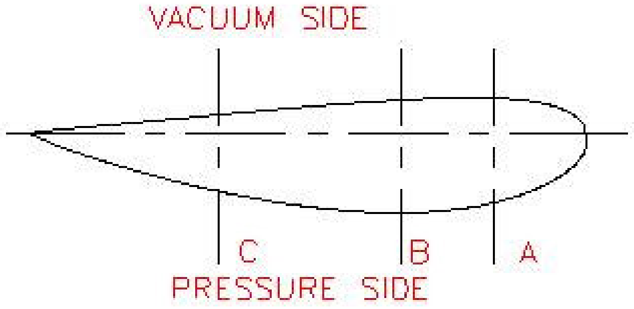
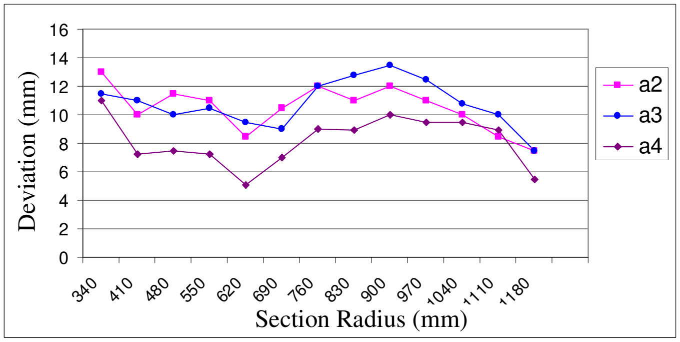


Figure 6. Aerodynamic profile with measure points.

Blade geometry influentiates directly at the fan aerodynamic performance. Some variation at the blade profile, at twist, chords and the manufacturing blade process affects the aerodynamic behavior of a fan, which made us to evaluate possible geometry deviations against the proposed blade design.

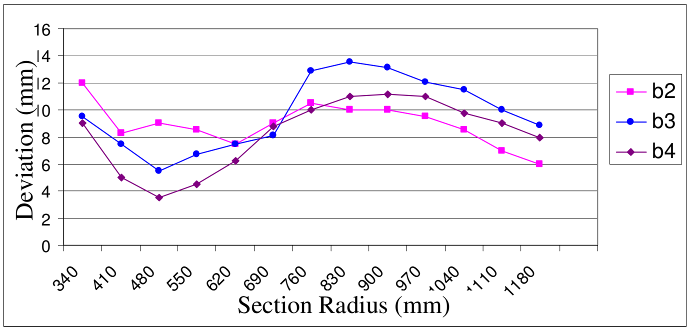
After the bade conformation, deep-drawing depth measures were performed at the conformed plates with use of models which are laser cut thin plates with the same aerodynamic profile of the blade design. This way, it was evaluated the depth variation in three specific points called “a”, “b”, and “c”, equidistant in each section of the conformed plate of a total of thirteen sections. These points are shown at Fig. 6.

The deviations measured were put graphically to facilitate the aerodynamic profile variation analysis. Thus, Graphs 1 and 2 shows the deviations which occurred during deep-drawing processes compared to the proposed aerodynamic profile at positions a, b and c in each conformed plate considering the send, third and forth tests.



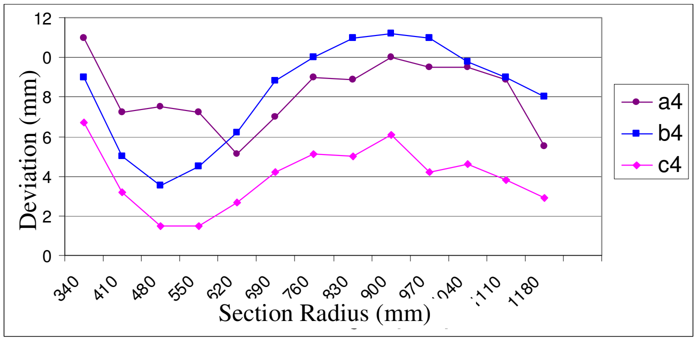
Graph 1. Deviations in position “a” – a2 refers to sheet 2, a3 to sheet 3 and a4 to sheet 4.

Observing the deeper deep-drawing is located at position “a”, can be noted, by Graph 1, that Sheet 2 had less deformation for insufficient load, followed by Sheet 3 which was a bubble formation mainly at radius region from 410 to 620mm. In addition, Sheet 4 had bigger deformation and, consequently, less deviation to the profile design.



Graph 2. Deviations in position “b” – b2 refers to sheet 2, b3 to sheet 3 and b4 to sheet 4.

At Graph 2, it is found a very similar behavior among the conformed sheets by the measured radius. However, the graph shows that, for SAE 1020 (Sheet 2), the elastic recovery effect is lower, since that, at less necessary load for conformation regions, i.e., up to 830mm radius, it was obtained the most depth conformations. The measures shown also indicate the deviation compared to the aerodynamic design can also be associated by some manufacturing deviations at punch, at die, or even by misalignments.



Graph 3. Deviations to be compensated at matrix– a4 refers to position “a” at sheet 4, b4 to position “b” and c4 to position “c.

Without concerning to study the causes and its roles at the deviations observed, but just looking at correcting them, it would be recommended to consider only the measurements made at Sheet 4 , which could let us to modify the matrix shape in order to compensate possible manufacturing, misalignment and elastic recovery effects. Thus, the data to be compensated can be seen at Graph 4.

In order to minimize the misalignment between the punch and die, it would be recommended to use a rotula, mainly for a guided punch, to allow more freedom to the punch to press different loads in different positions during conformation up to a complete deep-drawing finish. By other hand, an elastomeric punch could be used for cost reduction and the complete fulfillment of the matrix by the elastomer.

It is important to emphasize the roles of elastic recovery and matrix deviations were not foreseen when the matrix were designed. However, the deviations to be compensated at matrix should be added to the influence of elastic recovery and process deviations. This way, after dimensional deviations of he punch, Graph 4 can be corrected to estimate the deviations caused by the matrix deformation and material elastic recovery.

5. CONCLUSIONS

By an industrial application of prototype development, this work proposes an alternative to the existent deep-drawing matrixes using a new manufacturing technology for fan blade conformation prototype matrixes. This technology presents a technological innovation using punches and dies made by composite materials, with high rigidity and compressive resistance. By using experimental tests, it could be shown the composite matrixes could comply with the conformation expectative. In addition, the composite matrixes have the facility in adjustments and design corrections and lower cost, which would be great value for prototypes.

By the sheet geometry analysis comparing to the aerodynamic design of the blade, it can be noticed the conformed plate had deviations to the proposed aerodynamic design associated to possible manufacturing defects at punch and die, misalignment between them and elastic recovery of the conformed plate after deep-drawing. However, the defects associated to lack of rigidity during the process were not studied.

By the deep-drawing process, it can be post the matrix made by fiber reinforced plastic especially reinforced against compression was experimentally effective having high rigidity, unless there was no structural stability analysis during the process, opting only to correct any deviations in order to reach to a final product with the design dimensions.

However, some process adjustments can be made to facilitate the process as increase the punch way, control the blank-holder pre torque and introduce a mechanism to remove the conformed sheet without provoking deviations at the deformed sheet.

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