Numerical approach for thick plates manufacturing

Richard SPATARO[1], Pierre KRUMPIPE[1], Georges ROSSI[2], Louis MATHIEU[2]

[1]*CETIM (Centre Technique des Industries Mécaniques) – 7, rue de la Presse, BP 802, 42952 Saint Etienne Cedex 9, France*
URL: www.cetim.fr e-mail: richard.spataro@cetim.fr; pierre.krumpipe@cetim.fr

[2]*ALSTOM HYDRO – 82, Avenue Léon BLUM, 38000 Grenoble, France*
URL: www.hydro.power.alstom.com e-mail: georges.rossi-ext@power.alstom.com;
louis.mathieu@power.alstom.com

ABSTRACT: The construction of increasingly powerful hydraulic plants added to the ongoing research to cut manufacturing costs, requires the power station suppliers to develop and control new production technologies without delay. Therefore ALSTOM HYDRO in a continuous effort of R*D, has turned to numerical simulation using the FORGE®2005 software to define their production process for turbine blades. Modelling the forming operation allows manufacturing difficulties and die modifications to be anticipated. We use thermo-physical measurements and the setting of thermal exchange coefficients to then simulate the blade heat treatment. The relevance of the digital approach is confirmed by comparing the numerical results to manufacturing data.

Keywords: hydraulic turbines, blade, forming, cooling, FORGE®2005, expansion coefficient

1 INTRODUCTION

ALSTOM HYDRO is the world leading hydro power equipment supplier and service provider. Its product range covers large, medium and small hydro plants, as well as services and rehabilitation of existing plants. For their Hydraulic turbines and pump turbines up to 900 MW, they produce a large range of blades.

Together with traditional casting production, ALSTOM HYDRO is now developing manufacturing technology using thick plate hot forming processes. This approach results from research and development of new products or supplies. In order to optimize the material used and control the final blade shape, ALSTOM HYDRO wished to simulate the complete production cycle. This means two main steps as follows:

- plate forming
- heat treatment: controlled cooling

2 PLATE FORMING SIMULATION

2.1 Plate positioning at the start of forming

The used material is a stainless steel warmed to 1150°C. The 105-mm thick plates are previously obtained by rolling and are then flame cut to the profile specified by ALSTOM HYDRO. The greatest length is about three metres. The blade is shown in figure 1.

The dies are made with honeycomb structure.

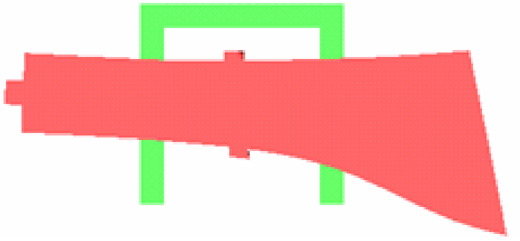


Fig. 1. initial plate shape

According to the difficulty of handling these parts in the factory with lift trucks, the plate's position and its stability on the forks of the handling machine or on the lower die, have to be ensured and easy to set up.

A simple calculation of gravity setting demonstrates the plate's instability when placed on the lower die. As shown in figure 2, the plate tips exceed Y axis.

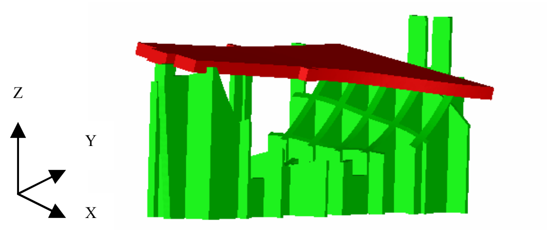


Fig. 2. Plate tipping

In order to avoid this matter, end stops are added along the Z axis. Figure 3 confirms that the plate's position at the start of forming is now ensured (included in the XY plan).

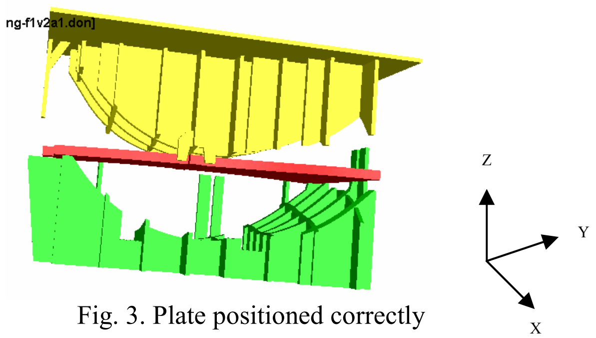


Fig. 3. Plate positioned correctly

2.2 *Slipping of the plate during forming*

The dies are specified so as to obtain a shape of plate that suits to the machined blade. Thus, as a consequence of the part's curved shape, it is essential that the formed plate remains strictly in the required position.

Figure 4 shows excessive slipping of the plate and thus a wrong final position on the lower die.

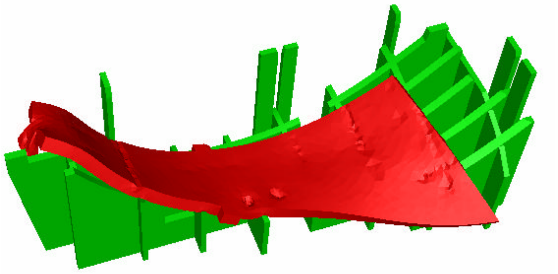


Fig. 4. Plate slipping

Because of the cut plate cost, any manufacturing scrap or over length is forbidden. Lateral stops are then settled to hold the plate during forming and hence obtain a suitable blade as shown in figure 5.

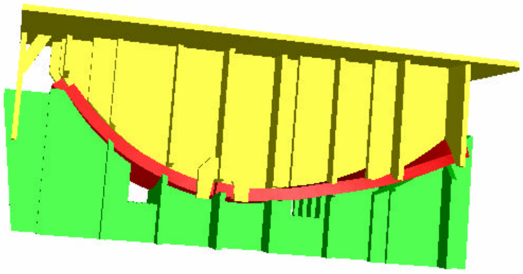


Fig. 5. Blade positioned correctly

These few die modifications, before their production, had limited the risks of plate scrapping in production.

2.3 *Forming force*

Using numerical simulation, FORGE®2005 software, we estimate the required forming force which increases very slowly to reach about 10,000 kN (1000 tons) at the end of forming (Fig 6).

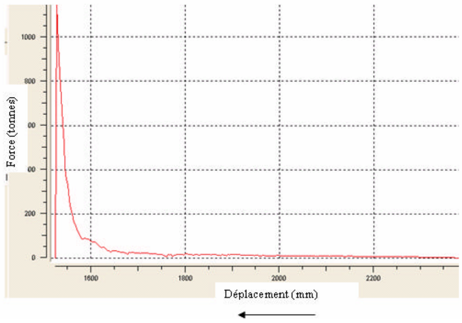


Fig. 6. Forming force

This result allows us to select the suitable production press.

These values will be confirmed later during initial blade manufacturing.

3 AIR COOLING SIMULATION

3.1 *Study hypothesis and thermo-physical data*

For this type of martensitic stainless steel, the heat treatment step involves a simple air cooling. We make the hypothesis that in a first approach, just taking into account the expansion coefficient change with temperature shows up the main distortions. Here micro-structural changes or other transformation plasticities are ignored.

Accurate expansion measurements are made using a NETZSCH DIL 402C "push rod" expansion meter. The results are shown in figure 7.

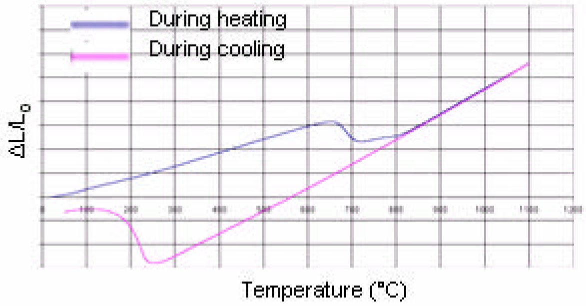


Fig. 7. Expansion measurement curves

These data are completed with specific heat and thermal conductivity measurements.

3.2 *Setting the heat exchange coefficients*

To reproduce in the best way the cooling conditions of the formed plate, we use temperature data supplied by ALSTOM HYDRO. These curves (temperature versus time) derive from thermocouples attached to a test sample, (fig 8), of the same metal as the designed blades and heated/cooled in the same conditions as all the manufactured blades.

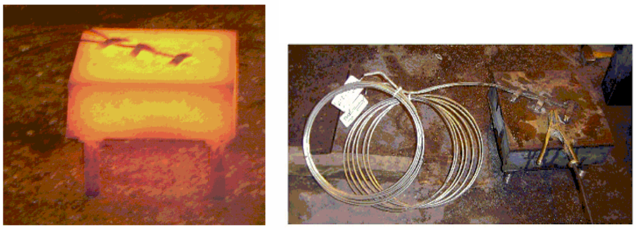


Fig. 8. Test sample

Meanwhile, we model this experimental test with FORGE®2005. The aim is to validate simulation input data by setting the numerical temperature curves in relation to the measurements. Then we introduce thermal coefficient values depending on the temperature of the heat exchange area. In addition, these values and those of the ambient temperature are different according to the exposed surface (facing the ground or free). By successive simulations, we obtain close digital/experimental curves, as represented in figure 9.

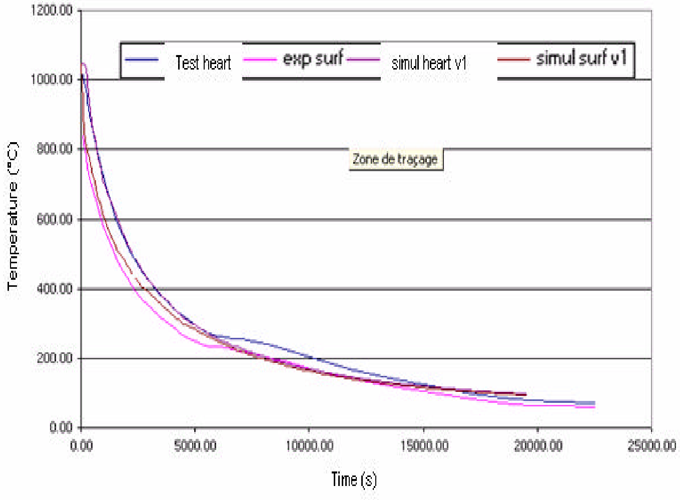


Fig. 9. Test sample

3.3 *Simulation results*

These settings, both for the material's thermo-physical characteristics and for the thermal exchange coefficients, allow to simulate the formed plate's air cooling phase. We see relatively uniform deformation (shrinkage). Nevertheless, plate contraction during cooling slightly alters its curvature, as we can see in figure 10.

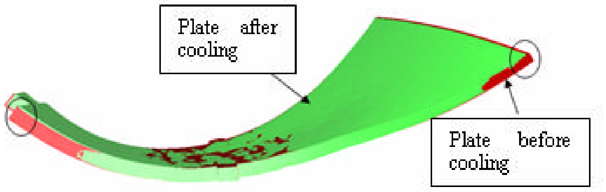


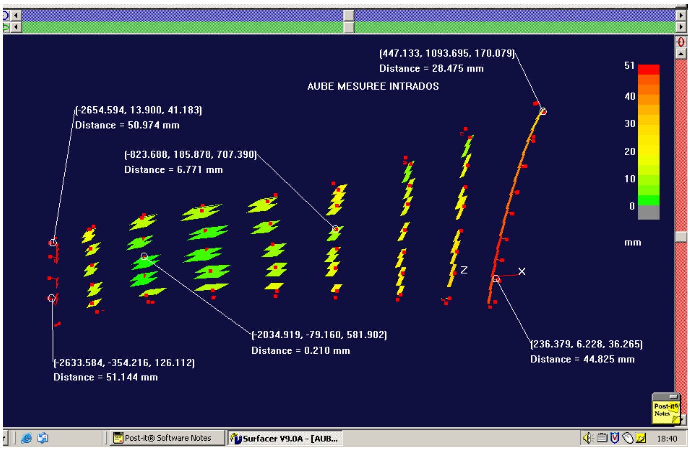
Fig. 10. Plate superimposition before (red) and after cooling (green)

Differences of about 10 mm appear at the ends. So, it looks important to take expansion coefficient effects into account.

4 DIGITAL RESULTS VALIDATION

The final geometry of the formed plate obtained by simulation is compared with the scatter plot constructed from digital sensing of the first manufactured blade. This was formed by the tools free from any manual reworking, and normally suits to the CAD specification used for the simulation.

Figures 11 below shows the differences observed on one side of the blade between the measured and theoretical values (a) and the numerical and theoretical values (b).



AUBE MESUREE INTRADOS

(447.133, 1093.695, 170.079)
Distance = 28.475 mm

(-2654.594, 13.900, 41.183)
Distance = 50.974 mm

(-823.688, 185.878, 707.390)
Distance = 6.771 mm

(-2034.919, -79.160, 581.902)
Distance = 0.210 mm

(-2633.584, -354.216, 126.112)
Distance = 51.144 mm

(236.379, 6.228, 36.265)
Distance = 44.825 mm

Fig. 11a Distance (mm) between the measured and theoretical blades

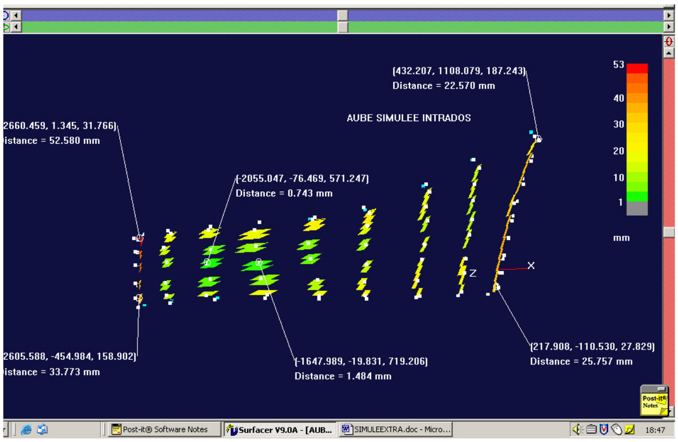


Fig. 11b Distance (mm) between the simulated and theoretical blades

Overall, the distance readings show the same trend. For example, we find again an area of low thickness in the middle of the blade near the narrow side (0.2 mm for measured blade and 0.7 for simulated blade). The maximum difference between the simulation and the measurements is about 5 mm.

5 CONCLUSIONS

Blade forming simulation, as a part of the development process, enables tool modifications before even the first manufacturing step. Following this production run (February 2007), the first part was declared good and only some slight tool modifications were made, unlike previous manufactures. Thus this study enabled cost and time savings.

Experimental data of temperature change with time allows us to set the thermal exchange coefficient values as precisely as possible. Combined with the measured thermo-physical values, these input data consolidate modelling of the process.

Multiple simulation/measurement comparisons lean us to the following conclusion :

- simulated plate seems to be quite close to measured plate. Thus, even if simulation cannot perfectly represent actual forming, this model seems capable of acting as a pre-validation of the forming plate. While allowing a safety numerical margin (3-4 mm), for new blade production ALSTOM HYDRO can validate or develop stamping device shapes for new blade production even before manufacturing.