3-Dimensional Forming of Thick Plates – A Comparison of Deep Drawing and an Approach of Rolling and Bending within a Single Process

Manuel Bojahr, Hannes Prommer, Ralf Tschullik, Patrick Kaeding
University of Rostock – Germany, Albert-Einstein-Straße 2, 18059 Rostock

Abstract:

A variety of industries require certain 3-dimensional formed thick plates, for example in shipbuilding for shell plates. Nowadays the production of curved ship plates is mainly based on the experience of the worker and is performed manually. The results are good and sufficient for the heretofore use in industry, taking into account that the number of curved plates with the same geometry is quite small. Moreover thick plates with a variable thickness are used for instance as so called longitudinal profiles for bridge building.
Currently the combination of curved plates with variable thickness does not meet a wide range of applications. But it has high potential in future. In modern shipbuilding this kind of plates offers special applications with a broad scope, e.g. reduction of weight. Renewable energies are another huge market in future.
Today, wind turbines are mostly made of glass or carbon fiber. The manufacturing process leads to high precision and quality of the final product. Nevertheless, this fabrication method of rotor blades is very cost intensive and its production technology is not the best in terms of recyclability. In addition to its good reusability, the handling of steel is well known and its fabrication is inexpensive.
Due to these facts an idea of rotor blades to be produced from steel arose. However, when desiring a huge output of a product with the same geometry a manual approach is inappropriate. A new process should be repeatable and within a certain accuracy. Deep drawing of the product is a natural choice but is not used for thick plates of enlarged sizes until now. This paper presents a comparison of deep drawing and a new approach. The developed process is based on a superposition of flat rolling and 3-dimensional bending. A major advantage of combining these steps is the opportunity to deliver formed plates with a variable thickness. This paper presents numerical simulations of deep drawing and rolling processes. The results are compared in terms of practicability for the production of rotor blades.

1.

1 INTRODUCTION

Renewable energies play a significant role in future energy plans. Wind energy is one of the most important branches and widely used. Considering that, it is a natural wish to get into that market. These constructions require certain three-dimensional shaped panels with variable thickness. Thus there are chances for modern shipbuilding industries to go into that business as well. For modern shipbuilding this kind of plates could also have a wide range of special applications. Those products do all have in common that they have a big market in future and desire a simple production process with a huge output which is not cost intensive. That means the process should be repeatable and within a certain accuracy without too much manual input. In addition the recyclability of such products came in focus so that the material chosen for the production should meet some requirements. Therefore the idea of rolling for a 3-dimensional forming with a variation in thickness of steel arose. The complexity of this approach is induced by the superposition of sheet forming with a rolling process. Furthermore degrees of deformation have to be realized which do not exceed the material's resistance; so the possibility of hot steel forming has to be considered. Due to the overall requirements deep drawing of the product, which is not used for thick plates of enlarged sizes until now, came in focus as well and was compared in terms of practicability.

Until today the desired outcome of the presented production approach is only achieved by the use of multiple processes. The thick plates for the bending process may be provided by a previous thickness variable rolling. For example so called longitudinally profiled plates [1] are already in use for bridge designs. Afterwards they are formed by an unpredictable sequence of manual empirical stampings which can take up to a day (Fig. 1). Despite the amount of time it takes, the results are good and sufficient for the heretofore use in industry, taking into account that the number of curved plates with the same geometry is quite small. However, there are two additional major disadvantages within this procedure concerning modern applications. On the one hand the accuracy of the final products is not high and not repeatable. On the other hand, the deformation degree which can be handled is quite low, due to the low manageable temperatures caused by the manual handling of the plates. Another method widely used in Asia which solves some of the mentioned disadvantages is line heating [2]. It is a technique used in shipyards for the forming of plates designated for ship hulls. The essential part is an iterative heat input along a predetermined path provided by an algorithm. Nevertheless line heating is not applicable to all forms and materials (e.g. aluminum) and moreover causes certain problems due to residual stresses and structural changes.

Abbildung 6 Auf dem Gesenk liegende und an 4 Strops angeschlagene Platte

Figure : Forming process of a thick plate

2 3-DIMENSIONAL ROLLING EXPERIMENT

Possible applications of the presented approach are for example small wind turbines. The desired rotor blades in this production process have a length of about 10 m. The negative contour of a CAD-design was assigned on two rolls. In this rolling experiment in a scale of 1:4 the rolls had to have a diameter of about 90 cm with a width of approximately 40 cm. Both rolls were arranged one upon the other in equivalence to a flat rolling process. The stamping force on the upper roll is applied by a shipbuilding press which can handle forces up to 5000 kN. To simulate hot steel, which should be used in a production process, lead was chosen as feed material for the experiments. The lead plates had a thickness of 25 mm and a length of 2000 mm with a width of 360 mm. The desired geometry of the blades requires a 3-Dimensional forming and in addition a variable decrease in thickness.

Results of the experiments showed that the process in general is feasible. But a few details of the experimental set-up have to be improved for further experiments: With the given machines it was not possible to hold the central axes of the rolls in a constant distance. So the stamping force was sometimes higher than necessary (up to 1800 kN compared to 750 kN which were calculated analytically as a lower bound) and consequently unrequested thickness changes happened. In addition, feeding and holding of the plates was performed by a side shift table. Fig. 2 shows the result of an experimental run. In Fig. 3 a simulation of a lead experiment is shown.

Figure : 3–Dimensional deformed lead plate

3 MODEL DEVELOPMENT

Prior to the experimental runs several simulations within different FE-Software were made to predict the forces needed and to observe possible side effects. For this purpose the manufactured rolls were measured by a light-pattern projector and the resulting data are used as input for the FEM solvers. With this given geometry the model is reduced, meshes are applied, boundaries are set and load cases are defined. The material used in the experimentally setup is lead and has a yield strength of 5 MPa. For the simulations an experimental obtained stress-strain curve is used. Due to the results of the simulations some important hints for the experimental runs were achieved. Moreover LS-Dyna was chosen as the solver for the 1:1 simulation of the real production process because of an internal benchmark. Besides, a deep drawing simulation of the same product was done to compare the feasibility. On account of the high deformation degree it is assumed here, that the feed material is already provided as a thickness variable plate.

Figure : Result of a lead simulation

As well as in the downscaled experiment, the rolling process is subdivided into two load cases: translation and rotation of the rolls. A schematic illustration is given in Fig. 4.

Figure : Loadcases

The translation of the rolls is important for the correct grip of the feeding material. In contrast to flat rolling the rolls cannot rotate whilst feeding due to their contour. The inlet was left unconsidered varying from the experimental setup. It is clear that this is only valid if the plate does not drift aside and will be implemented upon receiving the final construction plan.
Another important aspect is mass effects. A convergence study with different translation and rotation times is done. To avoid inertia effects in future simulations it is planned to alter the load cases. Both rolls are moving towards each other to obtain the correct gap between the rolls instead of moving the upper roll only as in the experimental setup. Furthermore, the rolling step itself is than superimposed by a displacement of the rolls' axes against rolling direction. That is to say that in contrast to the experiment the rolls are moving over the lead sheet. Using an explicit time integration scheme it is then possible to reduce the process time significantly because mass effects are negligible. Experimental material data for the simulation of the used hot steel is not available yet. So material data of S355J2G3 is used which is available in literature [3].

The FE-Model of deep drawing consists of three parts: punch, blank and die. The die is fixed in all degrees of freedom and the punch is also fixed except the vertical stamping direction. The chosen material model was the same as in the rolling simulation.

4 RESULTS

The primary fact for our research network was the force required to hold the upper roll with the necessary gap above the lower one. In addition, the reaction forces on the foundation during the rolling process are of major interest to plan full size versions.

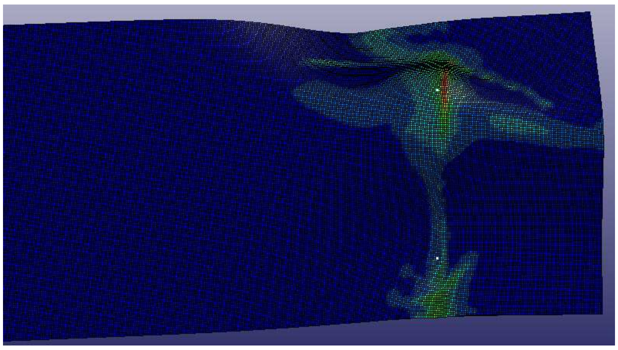
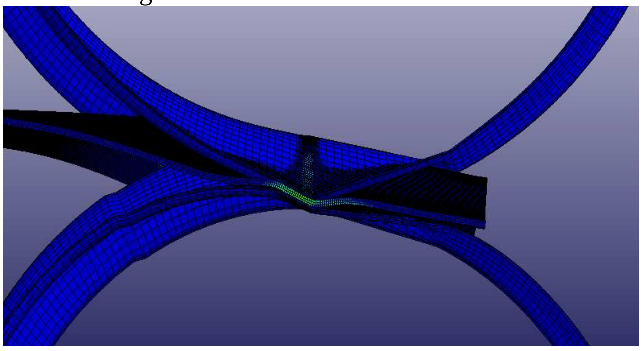


Figure : Deformation after translation



The crucial part within the simulation is the reduction in thickness. This graduation is the essential reason for rolling and leads to a massive increase of the reaction forces. That behavior is also illustrated in the graph presented in Fig. 6 where three simulations were normalized for comparison. At the beginning of the process only bending of the material is leading to an increase of the reaction forces visible at the standardized time 0.3 and shown in Fig. 5. Around 0.6 the graduation begins and the reaction forces rise to 145 000 kN. That results correlate with analytical evaluations obtained from flat rolling theory.

There are two more important aspects which can be obtained from Fig. 6. First, looking at the three simulations at around standardized time 0.3, it can be stated that there are mass effects. With increasing simulation times these effects are suppressed. It has to be mentioned that this was not considered in further discussions because this is not a key part for the posed questions, due to the fact that it has no influence on the absolute maximum value of the reaction forces at all.

The second aspect is the difference at the beginning of the increase within the three simulations. This is caused by a constant trise value of 0.1 in the DEFINE_CURVE_SMOOTH_TITLE keyword in all simulations while starting the rotation [4]. That means in all simulations the period of time to reach the necessary rotating velocity is absolutely the same. In contrast for the longer process time of 2 s the defined rotating velocity is in relative, reached earlier. And therefore the increase of the reaction force starts earlier in Fig. 6. And again this has no reasonable effect on the interesting maximum reaction force at the roll.

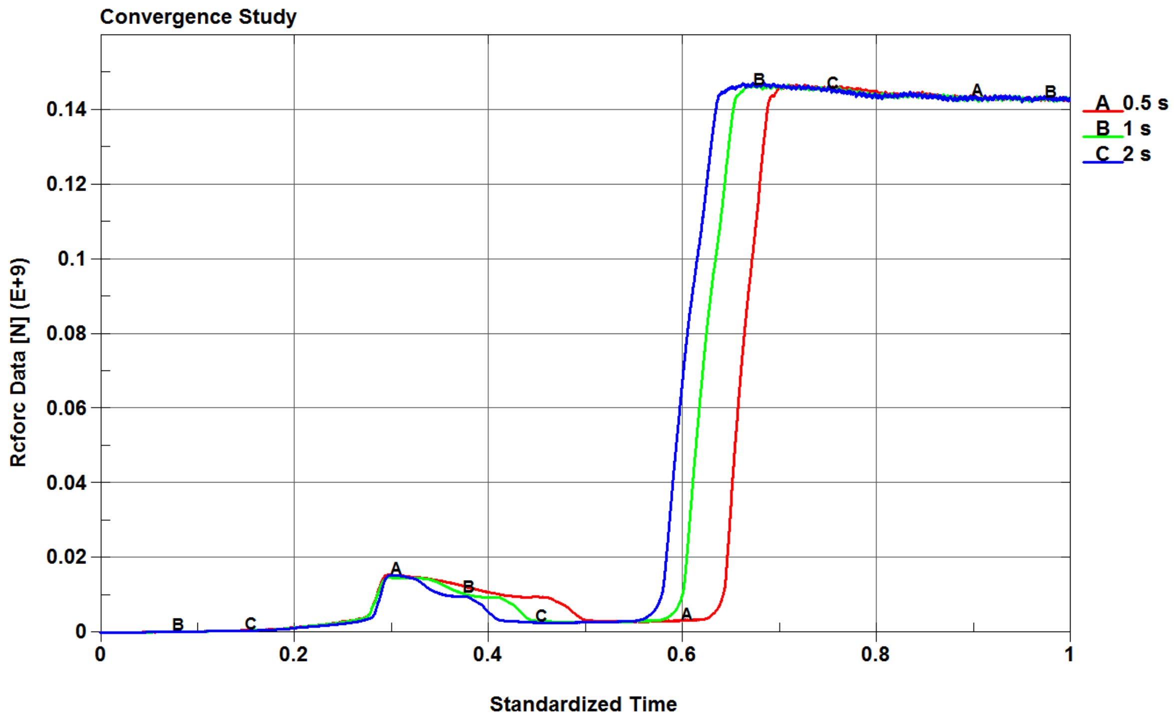


Figure : Convergence study

The results of the deep drawing simulation are presented in Fig. 7. The Idea is to split the coupled process in a thickness rolling process with a subsequent deep-drawing. The benefits are an easier fabrication process, combining two common ways of metal forming – although not for thick plates. Moreover the deformation degrees within the single forming steps are lower, so lower material temperatures are accomplishable. It came out that this separation in principle would be feasible. But the main disadvantage is the inflexibility of this approach. The tool size of about 10x2 m would be too huge for a cost effective change in geometry of the product. Also the area of deformation on the blank is bigger than in rolling where it is just a line in every step. Therefore the stamping force is orders of magnitudes higher than for the coupled rolling process.

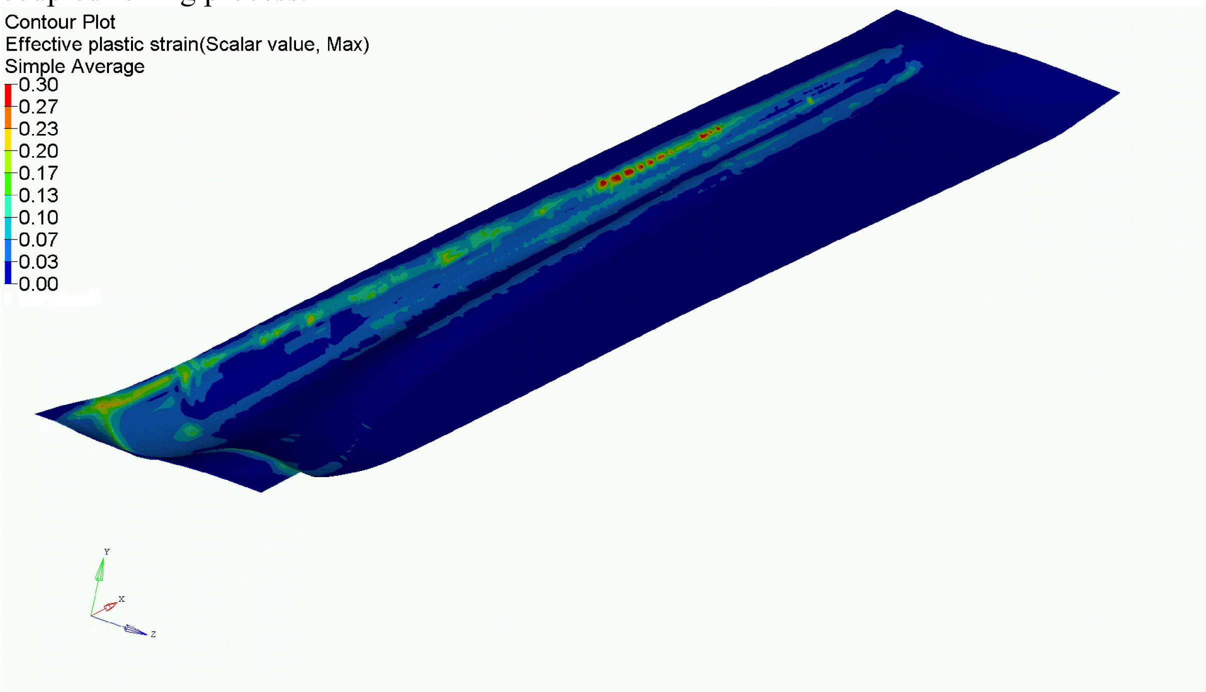


Figure : Deep-drawing of the same product

5 CONCLUSIONS

Forming simulations helped to prepare the experimental setup and showed effects which had to be taken care of especially when going into full scale. The obtained results also provide a strong argument for choosing the new production process rather than deep drawing. Not just the need of higher forces is crucial. Moreover it is the flexibility of the rolling approach. The contour of the rolls can be varied within a certain range whereas such a variation is not possible in deep drawing without huge investment.

The experiment and the simulations show that the approach of superposition of thick plate bending and rolling is working. Several inaccuracies have to be reduced for future experimental runs for a better evaluation of experiments and simulations. For our upcoming research we expect that taking gravitation and holding forces into account will change the end form of the plate but not the needed forces.

6 ACKNOWLEDGMENTS

The research presented in this paper is funded by the ministry of economics, labour and tourism of the German state of Mecklenburg-Vorpommern. The discussions with project partners are highly appreciated.

7 LITERATURE

1. J. M. Vigo, R. Hubo and J. Raoul, *Modern Steels for Constructional Bridges: Longitudinally Profiled - LP –* Plates, Journal of Constructional Steel Research, Elsevier, 1998, pp.403-403 (1)
2. C. D. Jang, S. C. Moon and D. E. Ko, *Acquisition of Line Heating Information for Automatic Plate Forming,* Crystal City USA: Ship Structure Committee Symposium, 2000.
3. Landoldt-Börnstein, Group VIII Advanced Materials and Technologies Volume 2C, Part1- Metal Forming of Ferrous Alloys, 2009
4. LS-DYNA Keyword User’s Manual, Version 971, Livermore Software Technology Corp., Livermore, CA, USA, May 2007