Production of blanks with thickness transitions in longitudinal and lateral direction through 3D-Strip Profile Rolling

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ABSTRACT: 3D-Strip Profile Rolling should enable the production of blanks with a defined thickness profile in latitudinal and longitudinal direction. The production chain of 3D-Strip Profile Rolling will combine Flexible Rolling in a first production step with Strip Profile Rolling in a second step. The control system to adjust the roll gap during 3D-Strip Profile Rolling is currently under development. Nevertheless, some first experiments have shown the general feasibility to produce 3D-profiled blanks. In 3D-Strip Profile Rolling the material will strain harden differently on different locations. This results in a variation of the material properties of the strip. Lateral spread, elastic roll stand deformation and local deformation will be influenced by this variation. To investigate these influences on the complete production process, the complete production chain needs to be modelled in the future with aid of finite element simulations. In this publication a first simulation model is used to study the influence of different grades of strain hardening in a Taylor Rolled Blank on the bulge formation that occurs during the rolling of a rill in this Tailor Rolled Blank.

Key words: Flexible Rolling, Strip Profile Rolling, 3D-Strip Profile Rolling, 3D-profiled blanks

1 INTRODUCTION

The combination of Flexible Rolling and Strip Profile Rolling should enable the production of strips with a thickness profile in latitudinal and longitudinal direction. This paper focuses on a concept to manufacture 3D-profiled blanks. First investigations on 3D-Strip Profile Rolling aim to show the feasibility of a coupling between Flexible and Strip Profile Rolling in one production chain. This paper presents the first results obtained by basic experiments, numerical analysis and their comparison.

2 STATE OF THE ART

2.1 Flexible Rolling (FR)

Flexible Rolling (Fig. 1) is based on the variation of the roll gap in a defined pattern during flat rolling [1]. It is applied to produce blanks with longitudinal transitions only, so called Tailor Rolled Blanks (TRB). During the rolling of the blanks, the thickness of the blank coming out of the roll gap is measured directly. An integrated algorithm conducts the variance comparison of the demanded profile online. With the ascertained failure the automatic gauge control is modified by changing the distance between the rolls.

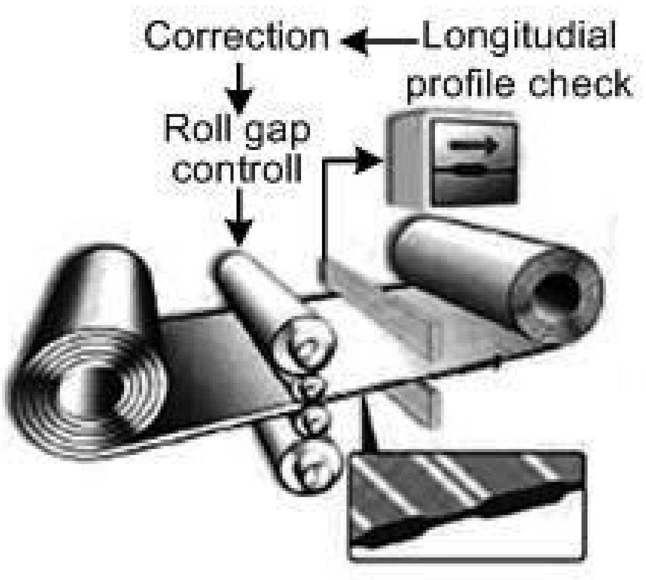

Fig. 1. Control system for the production of blanks with longitudinal thickness transition [2]

2.2 Strip Profile Rolling (SPR)

Strip Profile Rolling is applied to produce strips with defined thickness profile in latitudinal direction.

This continuous production process (Fig. 2) is based upon the utilisation of a roll system that causes a material flow in latitudinal direction [3]. The geometry of the forming rolls and the contact area are the two variables that mainly influence the latitudinal material flow. The ratio of contact width (b_d) to contact length (l_d) in SPR (Fig. 3) has to be significantly smaller than in common flat rolling, to obtain any material flow in latitudinal direction at all. In SPR an eventual material flow in longitudinal direction would cause flatness defects or even cracks. The high local thickness reduction causes to bulge formation near the rill [4].

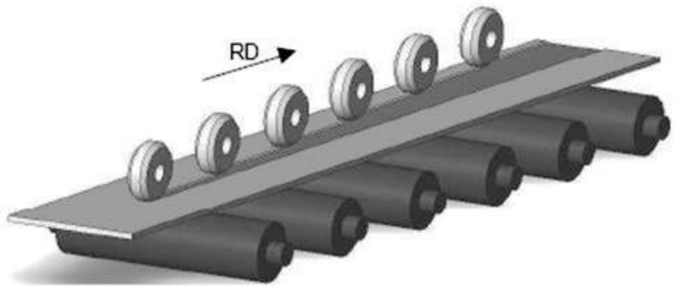

Fig. 2. Principle of production of blanks with latitudinal thickness transition [3]

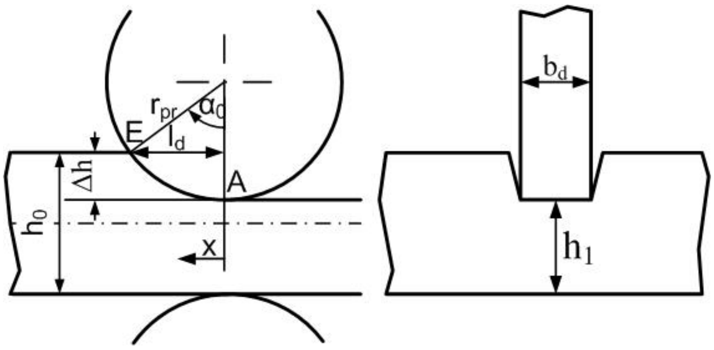

Fig. 3. Roll gap geometry in Strip Profile Rolling (SPR) left: longitudinal section, right: cross section [4]

3 CONCEPT OF 3D-STRIP PROFILE ROLLING AND THE REQUIRED CONTROL SYSTEM

3.1 Concept

By combining FR and SPR into one production chain it would be possible to produce blanks with both, longitudinal as well as latitudinal transitions. The process chain should exist of two sequent steps (Fig. 5). In the first step a longitudinal thickness profile is created by FR. Then, in the subsequent second step, a defined cross section is rolled in the strip by SPR.

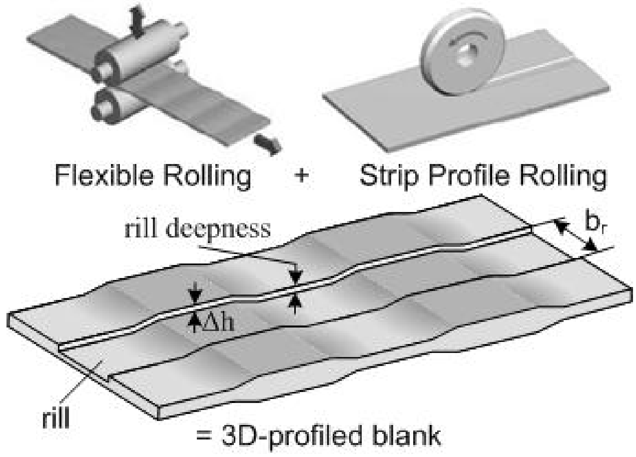

Fig. 5. Combination of Flexible Rolling and Strip Profile Rolling, product: 3D-Profiled Blank

Combining FR and SPR in one production chain brings several difficulties with it. On one hand the FR changes the material behaviour of the strip in a discontinuous way. TRB regions that have been reduced maximally in thickness (the thin regions) will have a higher yield stress as the regions which have been minimally reduced (thick regions) due to the strain hardening. This discontinuous material behaviour will effect the deformation, the lateral spread and the elastic roll stand deformation in the second SPR step. On the other hand, the thickness differences in rolling direction after FR bring the necessity to adjust the roll gap during SPR in order to enable the rolling of a rill with constant depth (or with a predefined varying depth).

3.2 Control system for the manufacturing process

To enable the production of 3D-profiled blanks a new control system has to be developed. The functional principle of the required control system is shown in Fig. 6.

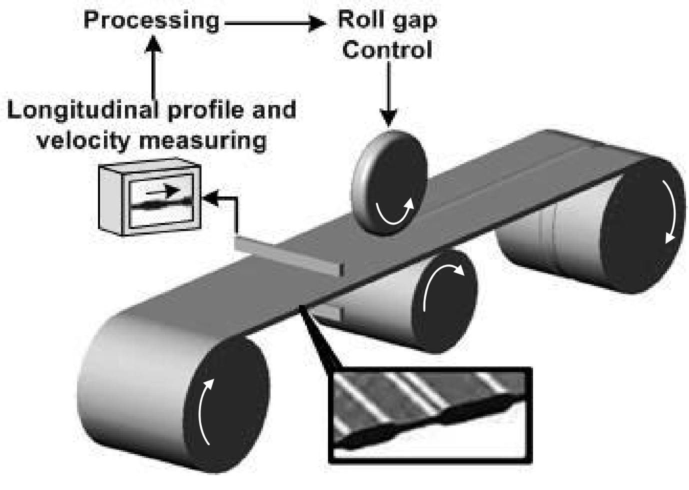

Fig. 6. Required control system to adjust the roll gap during Strip Profile Rolling of Tailor Rolled Blanks

The realisation of this concept is subject of matter of work being currently done. The new conceptual

control system for 3D-Strip Profile Rolling focuses on the second step in the process chain where a rill is rolled in the TRB. Therefore the control system measures the thickness and velocity of the TRB which enters the roll gap. An integrated algorithm performs the adaptation of the roll gap during SPR in the second step of the process chain.
A first concept of the control system for 3D-Strip Profile Rolling is currently available and has been tested in some preliminary tests. One of the results of these experiments is presented in Fig. 7. It shows the longitudinal profile on the surface of the TRB and on the bottom of the rill. From Fig. 7 can be seen that the control system for dynamic roll gap adjustment in the second SPR step is capable to adjust the roll gap so that a rill of constant depth is rolled in the TRB.

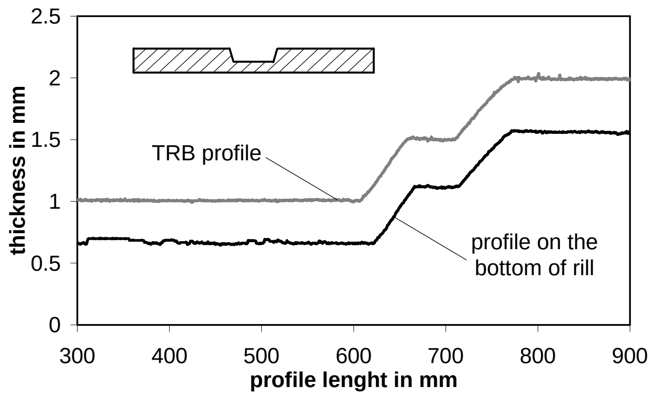

Fig. 7. Profile thickness in longitudinal direction on the surface of the TRB and on the bottom of the rill

4 EXPERIMENTS AND SIMULATIONS

4.1 Experiments

In order to investigate the latitudinal material flow in SPR of a TRB first experiments are conducted with a constant roll gap height (Fig 8). Emphasis of the experiments is put on the differences in bulge formation in the thick and thin regions (region A and B respectively in Fig 8) of the TRB. The thickness of the TRB in the thick region (region A) is 2.0 mm and in the thin region (region B) it measures 1.4 mm. In the transition region (region C) the thickness increase ratio equals 1:100. The width of the TRB is 100 mm.
The latitudinal geometry of the profiled TRB was measured with aid of a Nokra thickness measuring laser. Two measured geometries are exemplarily shown in Fig. 11 and 12 for the thick and thin region respectively. The measured geometries are used for comparison with numerical simulations of the experiments.

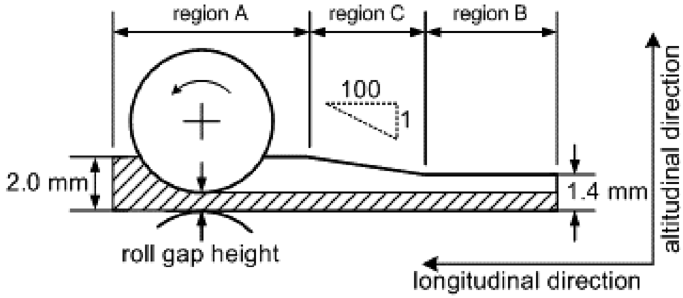

Fig. 8. SPR of a TRB with constant roll gap height

4.2 Finite element model

The experiments are numerically simulated with aid of finite element simulations in order to obtain detailed information about the local material flow, strains and stresses. The developed FE model (Fig. 9) consists of a cylindrical bottom roll, a profile roll and a TRB. The simulation proceeds in two steps. In the first step the blank is inducted into the roll gap with a defined velocity equal to the roll's peripheral velocity. In the second step the blank is caught up by the rolls and goes through the roll gap.

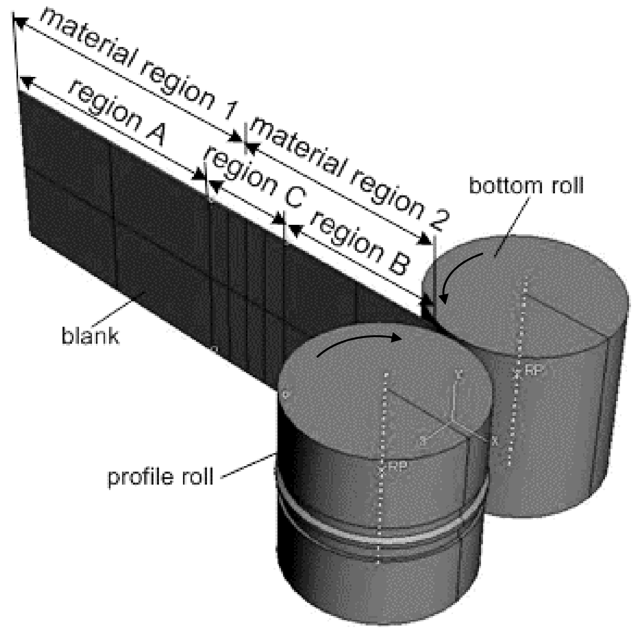

Fig. 9. The developed FE model

The material flow curve data is recorded in tensile test and is extrapolated. Because of different grades of strain hardening in the TRB, tensile experiments are conducted on specimens taken out of the thick as well as the thinner regions (Fig. 10). In the simulation model two material regions are defined. The yield curve obtained from the tensile specimens out of the thick region of the TRB are implemented in material region 1, the one of the thin tensile specimens to material region 2.
The profile roll and the bottom roll were constructed as analytic rigid bodies. The friction coefficient is

assumed to be constant and measures 0.1. The geometry of the TRB is identical to the geometry used for the experiments.

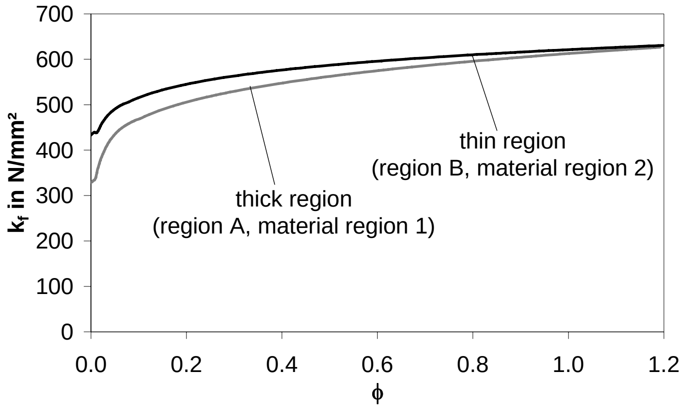

Fig. 10. Extrapolated yield curves obtained by tensile tests

4.3 Comparison of simulation and experiment

In order to verify the FE model, the calculated cross sectional blank geometry is compared with the one measured in the experiments. Emphasis is put on the area where the rill is rolled in the TRB. Fig 11 and 12 show the comparison between experiment and simulation for the thick and thin region respectively.

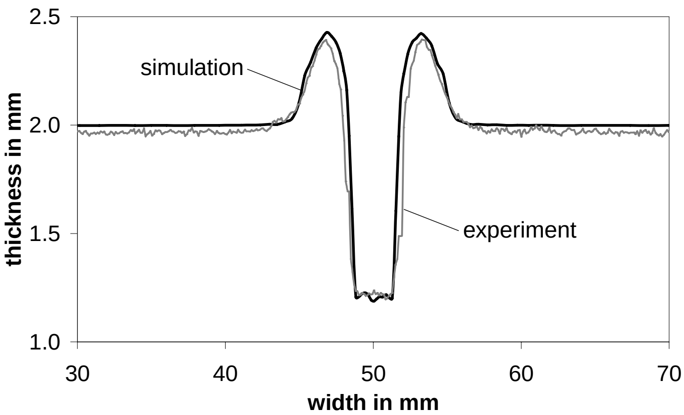

Fig. 11. Comparison of the cross sectional blank geometry in the direct environment of the rill in the thick region of the TRB

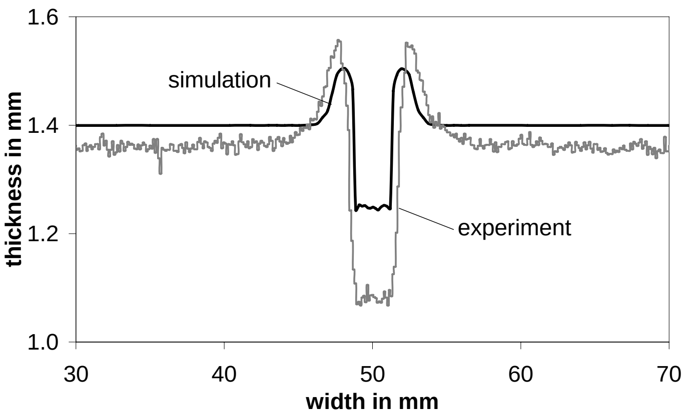

Fig. 12. Comparison of the cross sectional blank geometry in the direct environment of the rill in the thin region of the TRB

In the thick region of the TRB (region A) the cross sectional profile near the rill calculated by the numerical simulation of the SPR is in good agreement with the one measured from the experiments (Fig. 11). For the thin region of the TRB (region B) however, there exists a deviation between calculated and measured profile. This deviation can be explained by the elastic deformation of the rolling stand under load.

Due to the strain hardening imposed by the FR, the yield stress in the thinner region (region B) is significantly higher than the yield stress of the thick region (region A). The height reduction is bigger in region A then in B and consequently the contact surface between roll and TRB in bigger in region A then in B. The hypothesis to explain the deviation is that despite the smaller height reduction and contact area the rolling force in region B increases due to the increased yield stress and so exceeds the rolling force of in the thick region. As a consequence the elastic deformation of the stand is bigger.

5 CONCLUSIONS

3D-Strip Profile Rolling is a promising combination of Flexible Rolling and Strip Profile Rolling and offers the opportunity for further optimisation of products. A concept for a suitable control system is introduced and first experiments under idealised conditions have shown the feasibility. Rolling experiments and numerical simulations show coupling two rolling processes in a production chain interact and influence each other. The strain hardening in the rolling of a TRB significantly influences the bulge formation in the adjacent profile rolling step.

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