Novel method for obtaining the mechanical and topographic properties of strip within one process step

With the increased use of high-strength strip steels and the high surface texture requirements now demanded, three main problems arise in the skin pass process: high-strength steels require higher roll forces to generate strip yielding, resulting in extreme roll wear and hence more rapid deterioration in roll texture and hence more frequent roll changes. A novel Hybrid process has been developed which combines the skin pass and the levelling processes into one unit, but maintains independent adjustment of each.

Authors: Volker Diegelmann, Gerald Zwickel, Michael Ullrich, Helena Gouveia, Udo Weirauch, Klaus Boguslawsky and Alpha Verónica Pernía Espinoza

The elimination of yield elongation with the appearance of Lüder's lines and surface texturing on strip is typically performed in a 2-high skin pass rolling mill. To produce the highest flatness requirements, a subsequent tension levelling process is also applied. Soft steel grades, requiring only small skin pass deformations, are rolled with only light roll forces, thus roll wear and roll texture degradation is relatively low and the texture transfer from roll to strip is limited.

However, with the increased use of high-strength steels and the high surface texture requirements now demanded, three main problems arise: high-strength steels require higher roll forces to generate strip yielding, resulting in extreme roll wear, and hence more rapid deterioration in roll texture, and thus more frequent roll changes.

It has been shown that the mechanical characteristics of strip material after a skin pass rolling process can also be achieved during a pure tension levelling process by variation of applied tension and bending load **[1,2]**.

The realisation of the desired surface texture requires an additional superimposed deformation under pressure introduced simultaneously in those strip sections where the yield strength of the material already is met by the applied tension-bending procedure.

With funding from the European Union's Research Fund for Coal and Steel (RFCS), research was conducted into a new strip finishing procedure which combined skin pass rolling and tension levelling into one production step.

RESEARCH PROGRAM

The work was sub-divided as follows:

- Design, construction and implementation of new facility
- FEM simulation
- Pilot plant trials for process and process model development
- Trials and trial evaluation
- Comparing tests with conventional process.

An existing BFI pilot plant for tension levelling was modified to run the trials. The design, construction and implementation were carried out by Andritz Sundwig and supported by FEM studies from University Rioja using ABAQUS® software. The pilot plant trials were conducted by BFI to identify the process parameters for optimum strip quality, starting at default values deduced from FEM modelling. A sensitivity study for the existing process parameters was performed, along with further optimisation of identified process parameters using statistical methods. Set-up and control model basic developments were also carried out.

The newly developed process was evaluated by running comparison tests with the common skin pass rolling process. Bilstein, as a producer of cold rolled steel strip, carried out this part of the work together with BFI. The resulting material properties were investigated by ISQ using tensile test facilities, micro hardness measurement devices, alternating bending devices, metallographic methods for microstructure identification and by BFI using 2D/3D topography of the strip surfaces.

ISQ additionally investigated typical strip processing applications, such as deep drawing, painting and bonding behaviour. Bilstein supported the experimental procedure by material selection and supply, and material mechanical tests.

DESIGN AND CONSTRUCTION OF THE HYBRID FACILITY

The design of the tension levelling-skin-passing unit comprises two bending cartridges and two skin-passing cartridges. One pair of cartridges, each consisting of a bending and a skin-passing cartridge, is arranged hydraulically adjustable against each other in a vertical direction (see *Figure 1*). To skin-pass both sides of the strip, one cartridge is above the strip passage line, and the other one below, as shown in *Figures 2* and *3*. The arrangement of all four cartridges is shown in *Figure 4*.

The bending cartridge consists essentially of an 80mm ø bending roll with end-bearing assemblies to accommodate the axial forces, and two 90mm ø back-up roll rows which support the radial force components. The skin-passing cartridge consists of a 300mm ø skin-passing roll (textured) including bearing assembly to accommodate the axial and radial loads as well as two 100mm ø bending rolls which can be pivoted around the centre of the skin-passing roll into the strip.

Depending on the pivoting angle, the degree of overlapping (wrap angle) of the two upper 100mm ø bending rolls and the lower 80mm ø bending roll, varies. Thus the bending/tensile stresses in the strip cross-section can be modified. At maximum overlap, a maximum wrap angle of 71° is possible. A plant schematic and operating details are given in *Figure 5* and a photo of the unit in use shown in *Figure 6*.

FEM SIMULATION

The simulation of the hybrid process served to support the design and construction process. It was essential to select a constitutive law able to reproduce strip behaviour under cyclic load. The theory of Chaboche **[1]** includes a 'non-linear kinematic hardening rule' to represent the change of the yield surface centre (evolution of the back stress tensor) according to plastic strain, and an 'isotropic hardening equation' to take into account the change of the yield surface radius. In this way the model is able to reproduce several important material characteristics, such as the Bauschinger effect.

Model adaptation to real conditions was done by low cycle fatigue tests performed according to ISO 1099-1975 international standard to identify the model parameters **[2]**. The developed FE model enabled the analysis of arising stress and strain within the strip during and after processing. Additionally, this model served as a basis for the development of a roughness transfer model using the sub-modelling tool provided by ABAQUS®.

Running a global simulation with work rolls having a smooth surface, the boundary conditions could be deduced for further use within a local model. This model

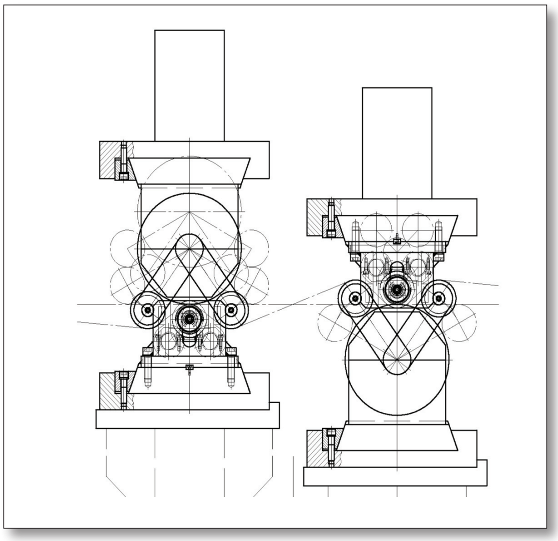


Fig 1 Cartridge arrangement

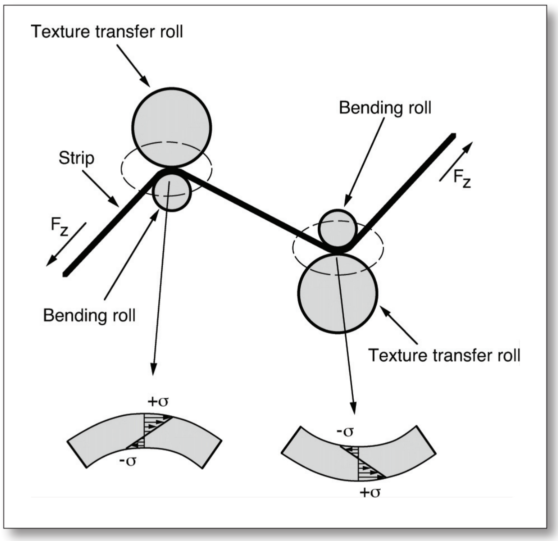


Fig 2 Bending of upper and lower strip surfaces

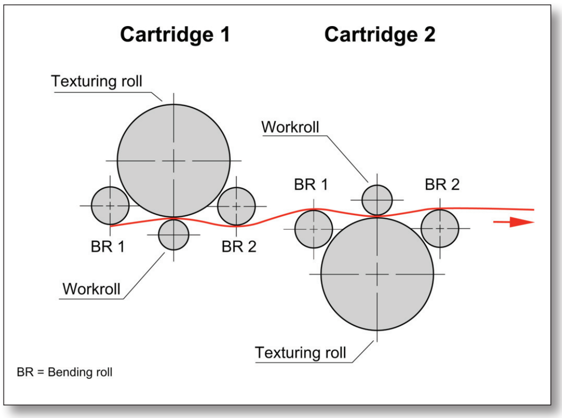


Fig 3 Schematic of roll arrangement and strip contour

▷

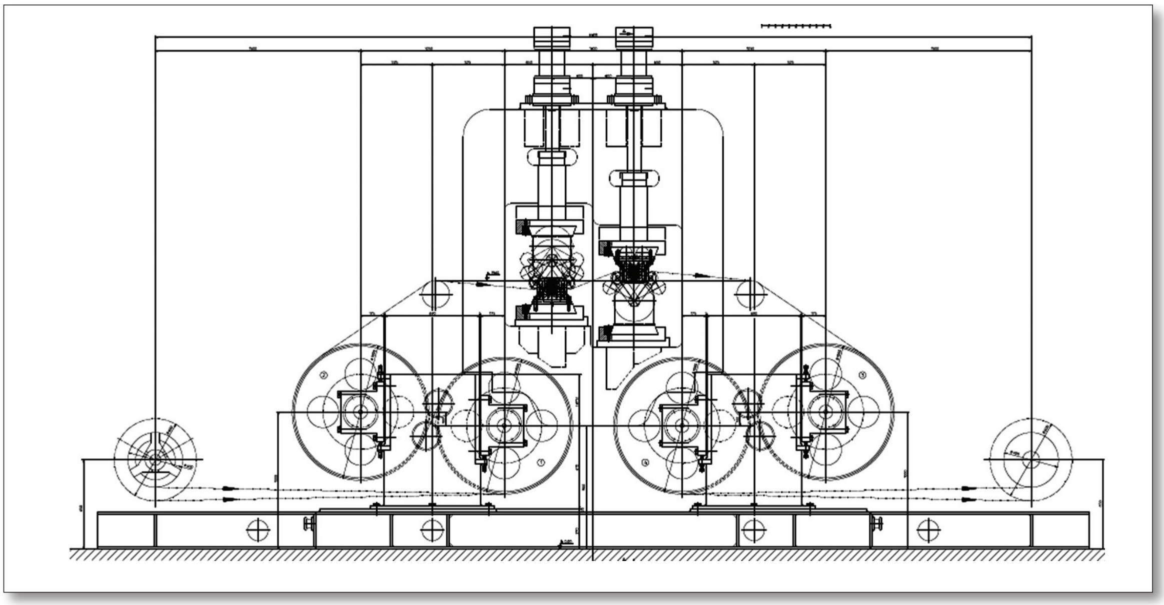


Fig 4 **Technical drawing of pilot plant**

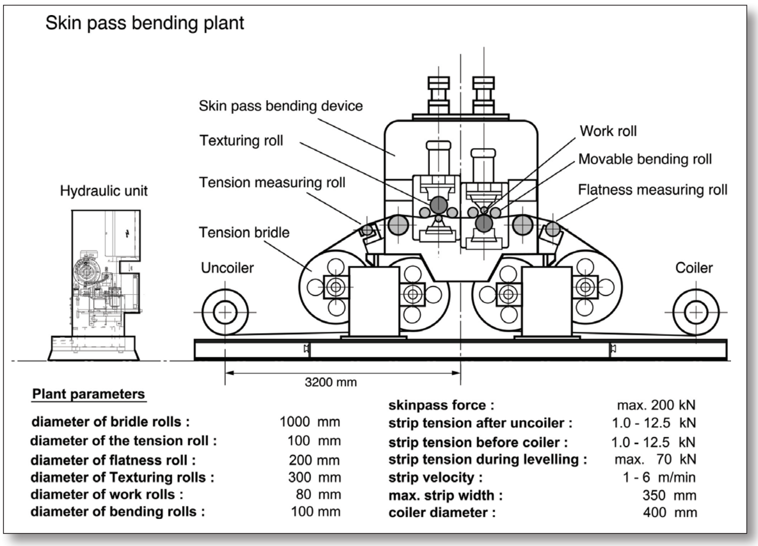


Fig 5 **Pilot plant technical details**

used data from measured roll topography to reproduce the work roll texture and pilot plant tests provided data for model validation. The global model is shown in *Figure 7* and the strip roughness at the end of the simulation with work rolls is shown in *Figure 8*.

TRIALS AND EVALUATION

In total, 162 plant trials were run with two steel grades DC04 (soft) and ZSTE800 (high strength).

The thickness-width dimension for the DC04 was 1mm x 200mm and the ZSTE800 was 0.8mm x 150mm. The trials were run by varying the applied tension, the degree of bending and the roll force. The DC04 was investigated under symmetric and asymmetric bending roll adjustments respectively (asymmetric bending roll adjustment describes the fact that bending roll 1 (BR1) and BR2 were penetrated with different degrees. This was done because of BR1 having an impact on the yielding behaviour of the strip). The ZSTE800 was investigated only under symmetric bending roll adjustments.

Specimens were taken from the rolled strip reflecting different parameter combinations. These were focused on the optimum adjustment of the bending rolls and texture transfer roll force in order to run the facility with lowest required elongation and at the same time with optimum roughness transfer. Roughness transfer from roll to strip was evaluated by 2D/3D surface analysis using mechanical and laser optical devices.

COMPARISON WITH CONVENTIONAL PROCESS

The new hybrid process was compared with conventional skin pass rolling process by running industrial trials at the Bilstein facilities using steel grade DC04. Three different campaigns were undertaken applying a range of roll forces and tensions. Tension was adjusted 50% above and 50% below the customary level. The skin pass required and the strip roughness were chosen as the target parameters for further assessment.

During each campaign the skin pass reduction was varied from 0.4% to 2% in steps of 0.2% and roll force measured under the given tension condition. Strip mechanical properties were also determined for comparison.

RESULTS

Based on a statistical analysis significant parameters having impact on the elongation degree and the roughness transfer were identified:

- Penetration depth of bending roll
- Applied longitudinal strip tension
- Texture transfer roll pressure.

Figure 9 shows comparative results for elongation and roll forces required for skin pass and hybrid systems. A 25% reduction in roll force is illustrated.

The strip topography was measured in both 2D and 3D. The roughness transfer was evaluated and was found to be good under the given conditions. Taking the common value for roughness transfer evaluation it was found that 30~60% roughness transfer did happen from roll to strip.

The roll lifetime investigation did not lead to significant results due to the comparatively low service performance of the textured rolls. Nevertheless, the roll topography was measured three times during the test period and the results for the test start and test end time are shown in *Figure 10*. The roll does not show a serious decrease

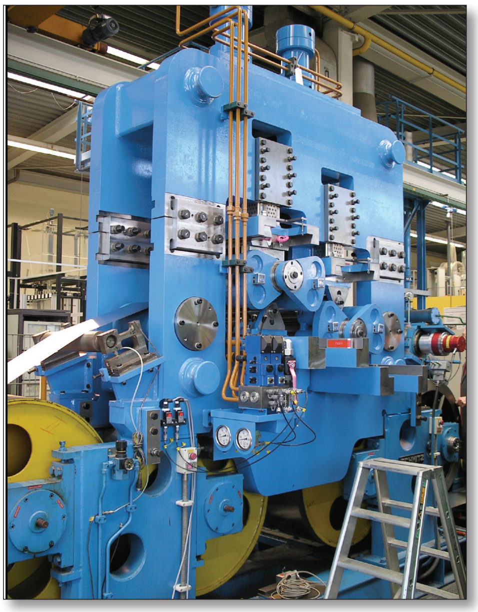


Fig 6 **Pilot plant in use**

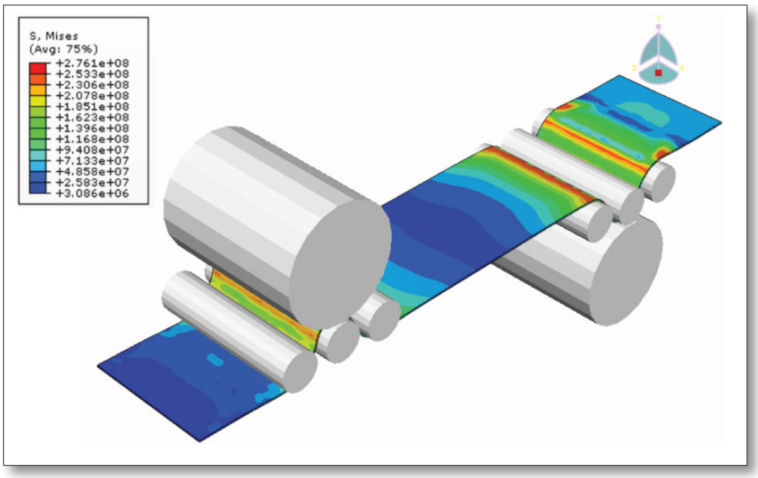


Fig 7 **General view of the global model (strip width 2mm)**

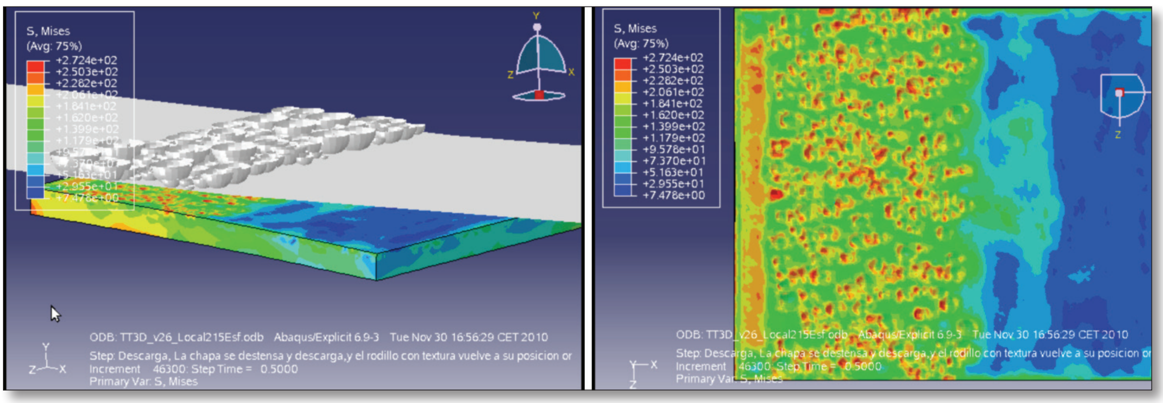
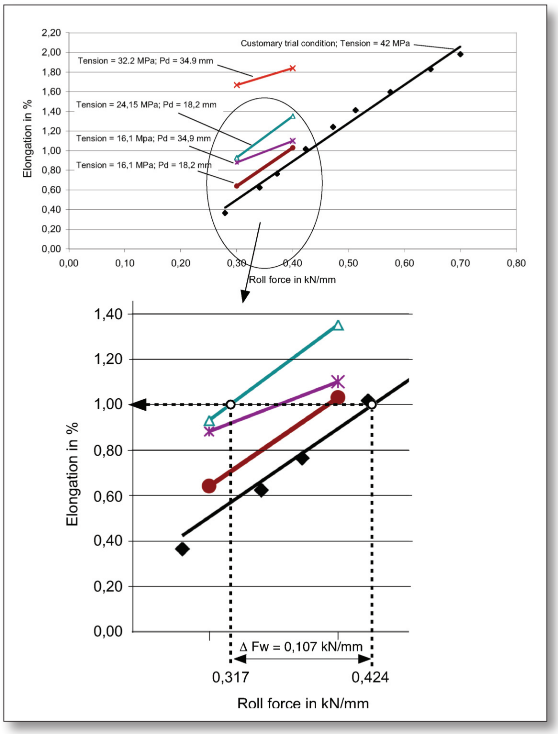
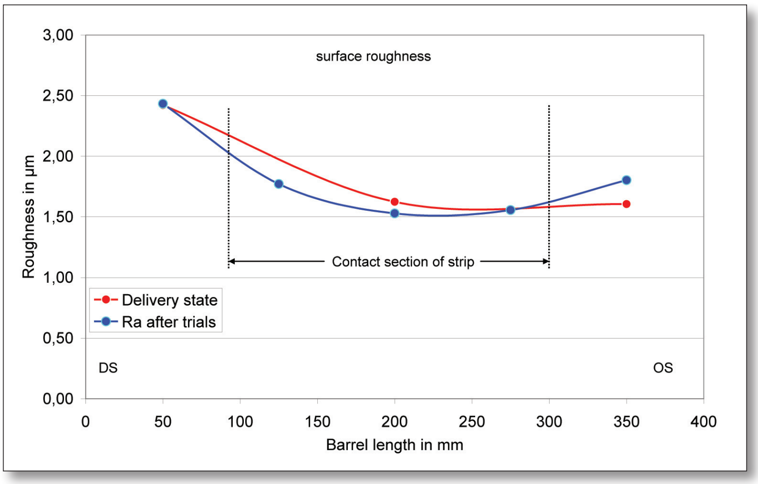


Fig 8 **FEM outputs showing the roll topography acting on the strip surface (*left*) and the indentations on the strip after processing (*right*)**



Ⓐ Fig 9 **Comparison of common skin pass and hybrid skin pass process elongation and roll force**



Ⓐ Fig 10 **Roll surface roughness**

in roughness. An investigation into strip flatness was initiated.

CONCLUSIONS

- A new strip finishing procedure combining skin pass rolling and tension levelling, into one production step has been successfully developed
- Strip elongation and roughness transfer are separately adjustable
- The skin pass power requirements were found to be ˜25% below typical skin pass values. Working parameters were identified, however, further optimisation, particularly of the process technology and the facility design, is required
- Strip mechanical properties show comparable behaviour to skin-passed material
- An investigation into strip flatness was initiated and will be further advanced
- Surface texture was found to be good, but with room for improvement. Better results would have been achievable with an optimised roll topography.

FUTURE OUTLOOK

The knowledge gained in this work will be built on and transferred to industrial scale by a continuing pilot plant project. Considerable efforts will be made in addressing strip flatness.

The research leading to these results has received funding from the European Union's RFCS research program under grant RFSR-CT-2011-00016. MS

Volker Diegelmann (VDEh-Betriebsforschungsinstitut GmbH, Germany)
Gerald Zwickel and Michael Ullrich (Bilstein GmbH & Co KG, Germany)
Helena Gouveia (Instituto de Soldadura e Qualidade, Portugal)
Udo Weirauch and Klaus Boguslawsky (Andritz-Sundwig GmbH, Germany)
Alpha Verónica Pernía Espinoza (Edmans Research Group, Universidad de La Rioja, Spain)

CONTACT: volker.diegelmann@bfi.de

REFERENCES

[1] J L Chaboche and G Rousselier, *Trans ASME J. press., Vessel Tech.*, 105, p153, 1983

[2] J W Morris, S J Hardy, A W Lees and J T Thomas, "Cyclic behaviour concerning the response of material subjected to tension levelling", in *International Journal of Fatigue*, 22, pp93–100, 2000