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THERMAL EFFECTS ON THE RUN-OUT OF CHILLED CAST THERMO ROLLS

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Abstract: *A downside of the widely used chilled cast iron thermo rolls is their tendency to deflect under thermal load. The roll body has a white iron surface layer and a grey iron inner layer. The thermal expansion coefficients as well as other material properties of these layers differ from each other. To understand the thermal deflection caused by the layer thickness variation, a FE model with two iron layers was created. The model is based on the results of an ultrasonic wall thickness measurement of a thermo roll. The thickness variation is interpreted as iron layer thickness variation. FEM software is used to analyze the deflection of the model at operating temperature.*

Key words: paper machine, thermal deflection, thermal deformation, ultrasonic measurement, FE model.

1. INTRODUCTION

1.1 Background

For many decades the chilled cast iron thermo rolls have been successfully used in calenders of paper machines. Although the number of forged steel thermo rolls is slowly increasing, the chilled cast iron rolls are still dominant in the paper industry, 99 % in 2004 [1].

There are four types of thermo rolls: centre bore rolls, displacer rolls, peripherally drilled rolls and externally heated rolls [2]. Modern thermo rolls are mainly peripherally drilled rolls or displacer rolls. Peripherally drilled rolls have usually 15...50 bores which are 20...60 mm from roll surface. The diameter of these bores is 25...50 mm. There are several designs for the heating fluid passages ranging from one bore per pass to three adjacent bores. With the increasing number passes the temperature drop from one roll end to the other can be controlled better. The heating medium used with thermo rolls is water, steam or thermal oil.

Chilled cast iron has been used for roll shell material because of its good manufacturability, low material cost and other good properties. The requirements for the properties of the thermo rolls are complicated. The roll surface should be extremely smooth, have good wearing and corrosion resistance, be shock resistant, and be easily cleanable. The strength of the material should be high with good thermal conductivity.

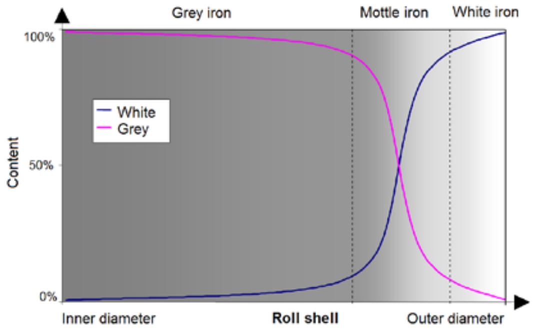

Fig. 1. Different layers of iron in the chilled cast iron. [3]

The chilled cast iron roll body has three different layers because of different cooling speed in casting process [3][4]. These layers give some of the desired properties to the roll. White cast iron layer on the surface (8...16 mm) give the required hardness and wear resistance and the grey cast iron inner layer is drillable. Between these layers there is a layer of mottle iron, an iron type where both white and grey irons are present (Fig. 1).

In addition to these desired properties there are harmful properties. The layers have different iron phases, different hardnesses and different coefficients of thermal expansion. Because of the varying thickness and depth of the layers, causing an asymmetrical arrangement of the layers, the roll, when heated, acts like a bi-metal and deflects. A thermo roll that has practically no run-out at room temperature can have a significant run-out at operating temperature. [4][5]

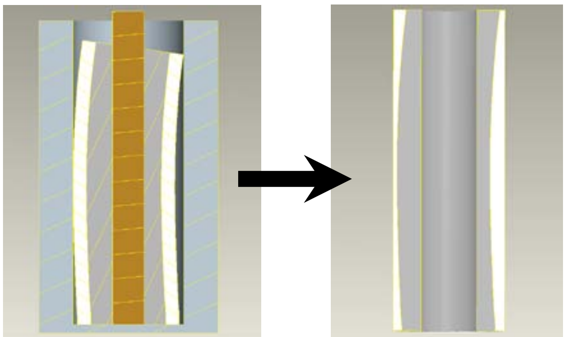

Fig. 2 Roll body in the mould (left) and machined (right).

The varying thickness and depth of the layers come from the casting process. The roll slab shrinks during cooling more than the chill mould thus releasing itself partly from the mould wall. In this stage only the surface of the slab is partly solidified while the bulk is still molten. Because of this the slab can buckle (Fig. 2). The partly solidified outer layer is mainly white iron and keeps its layer structure during the cooling period. When the roll slab is machined, it has a white iron layer on the outer surface that has a varying thickness. The deflection of the roll body appears in the direction where the layer thickness of the white iron has its local minimum.

To understand some of the unwanted properties like thermal deflection and oxbow-effect of the chilled cast iron rolls [6], FE models were created. The models are based on the ultrasonic wall thickness measurement.

2. METHODS

In this study a chilled cast iron thermo roll is used as a basis of a roll model. The body length of this test roll is 7.69 m and its diameter is 1.067 m. The distance between the bearing centre lines is 8.4 m.

2.1 Ultrasonic measurement

A new method of acquiring information about the layer distribution of white iron was studied in this work. It is based on the ultrasonic measurement of the wall thickness of the roll body. The speed of sound has a different value in the different layers of cast iron. It was assumed that the thickness variation is not caused by the thickness variation of the shell, but it comes from the thickness variations of the different layers. If the wall thickness of the roll body and the speed of sound in the different layers are known, then the layer thickness variation can be calculated from the ultrasonic measuring signal i.e. time of flight signal.

The roll body of the test roll was measured with an ultrasonic measuring device developed at the Helsinki University of Technology [7]. The measured map of wall thickness showed a thickness variation of ±2 mm, anyway the manufacturer of the roll has informed that the thickness variation is below 0.3 mm. This supports the layer thickness variation assumption.

2.2 The FE model of the roll

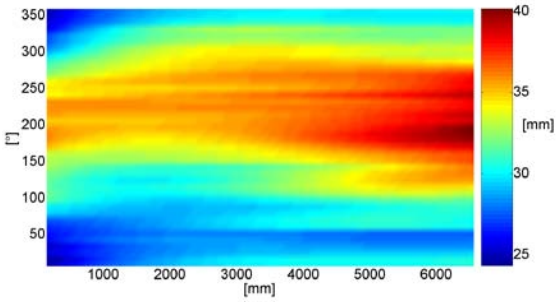

Fig. 3. This data was created from the thickness data and it shows the distance from the surface. It is used to create the boundary mesh between the iron layers in the model.

The dimensions of the roll model were taken from the test roll. The white iron layer thickness was calculated from the ultrasonic wall thickness measurement. The wall thickness data was converted to layer thickness data of the white iron (Fig. 3). To simplify the calculations, the roll body was treated like a body with two layers, see Fig. 4.

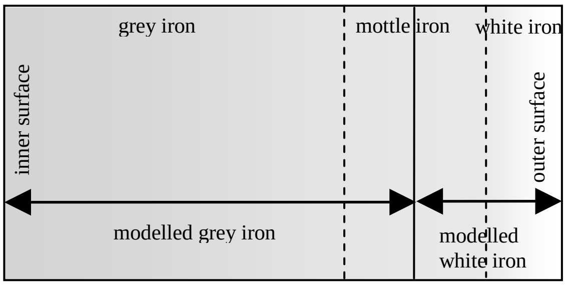

Fig. 4. Simplified shell layer structure for the model.

The layer data was converted to CAD-file (Fig. 5a.). The layer data model was converted to two solids for grey and white iron layers. Two roll end solids of steel were added (Fig. 5b.).

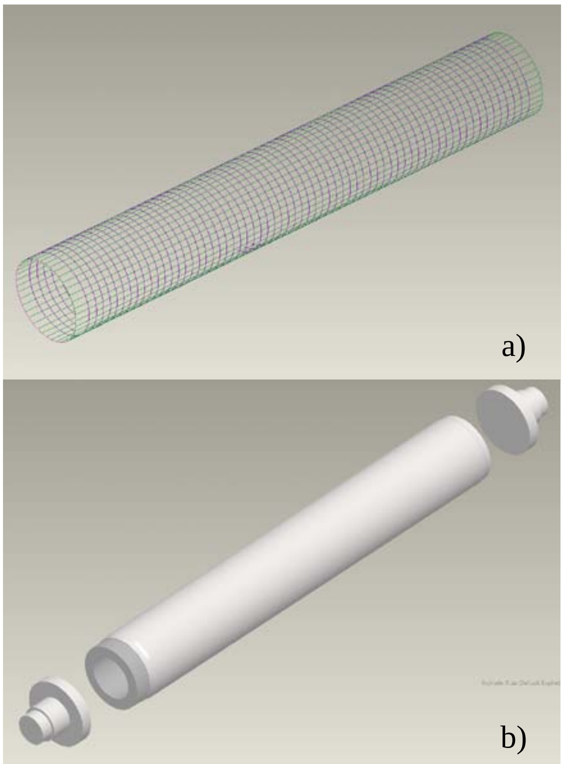

Fig. 5. a) The layer mesh used for both layers and b) the exploded roll body model with ends.

In the model the average white iron layer thickness was set to 16 mm. Two other roll models were created with different white iron layer thicknesses, one with an average layer thickness of 24 mm and the other with 36 mm. These layer thicknesses represent actual white iron layer thicknesses. As it can be seen from the Fig. 1 and Fig. 4 the modelled layer thickness is two times thicker, because half of the mottle iron is assumed to behave like white iron and half to behave like grey iron. This means that layer thicknesses in the three models are 32 mm, 48 mm and 72 mm respectively. These layers are created from the original layer by scaling.

	E [GPa]	ν	ρ [kgm^{-3}]	α [10^{-6}K^{-1}]	c [ms^{-1}]
white	172	0.27	7694	9.0	5796
mottle	131	0.27	7583	9.9	5198
grey	103	0.27	7334	10.8	4600
steel	207	0.30	7835	11.16	5900

Table 1. Properties of the iron phases and steel. [6]

The three models were used as input in Abaqus FEM software. Material properties are presented in Table 1. Properties of mottle iron are presented as additional information and as they are not used in the model. Temperatures used in the calculations are in the initial step 20 °C for all elements. In the next step the temperature propagates to 150 °C in the grey iron layer and to 125 °C in the white iron layer. In the final step all elements in the roll have a temperature of 150 °C. The chosen temperature values were measured from a thermo roll under operating conditions.

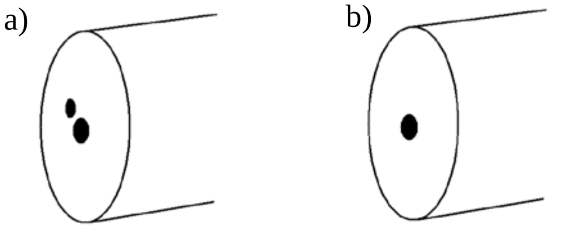

Fig 6. a) Axis end centre point and a secondary point locked, b) centre point locked.

The FE analyses of all three models were done with the same boundary conditions. The roll models were simply supported. This means that the centre points of the roll axis ends are locked. In one axis end all translation directions of the centre point are locked and in the same axis end a secondary point is locked in radial directions (Fig. 6a). The translations of the centre point of the other axis end are locked only in radial directions (Fig. 6b). This allows the roll to expand axially and keeps it from rotating, but does not prevent the deflection of the roll. They are interchanged in the second round of calculations. This is done to evaluate their influence on the results. Two point locking is applied in the first round of FEM analysis on the service side axis end and in the second calculation round on the drive side axis end. This evaluation is done only with 16 mm white iron thickness.

As discussed in the introduction, the chilled cast iron thermo rolls can deflect under thermal load in the paper machine. This deflection introduces run-out in the rotating roll. The first harmonic component of the FFT analysis of the run-out gives the amplitude and the phase (direction) of the deflection. [5]

The results from the FEM calculations were analyzed to find out any geometry changes in the roll body. These geometry changes can be observed as a run-out of the rotating roll. To find out the theoretical run-out of the roll model, the profile from 9 roll body cross sections were calculated from the result file of the FEM software. The first harmonic components of the cross section profiles were obtained with FFT analysis. The possible deflection of the roll model can be observed in these components.

3. RESULTS

The results presented here are the amplitudes and phases of the first harmonic components (1H) from the 9 equally distanced (0.8 m) roll body cross section profiles. Section 1 is on the service side 0.2 m from the roll body end and section 9 is 0.2 m from roll body end on the drive side.

In Fig. 7 there are the amplitudes and phases from the roll model with 16 mm white iron layer with both boundary condition sets and with both surface temperatures. In the two figures it can be seen that the chosen boundary conditions have only a small effect on the amplitude and phase. The maximum differences in the phases are close to the ends which is expected. The temperature difference in the iron layers increases the deflection of the roll. This is also expected, because the cause for the deflection is in the differences of the thermal expansion between the iron layers. The temperature difference increases the deflection.

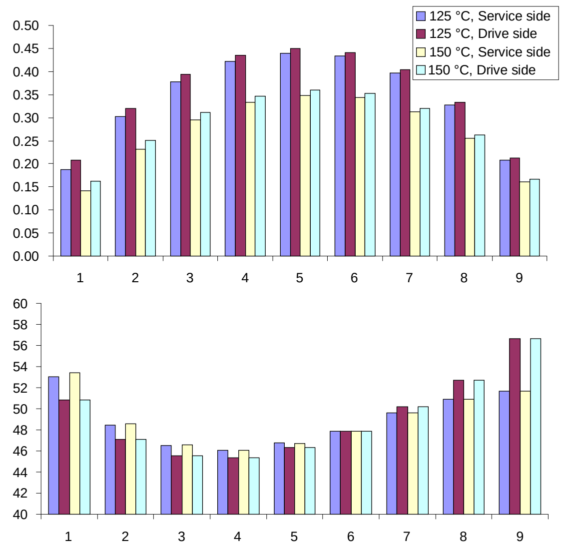

Fig. 7. The run-out of the cross sections of the 16 mm white iron model, 1H-amplitude [mm] (above) and the phase [°] (below).

In Fig. 8 there are the amplitudes and the phases from the models with different white iron layer thicknesses at 125 °C surface temperature. The results show that the thinner white iron layer gives a larger deflection. The different layer thicknesses have a negligible effect on the phases. When the temperature difference between the iron layers disappears (Fig. 9) the deflection decreases, but the direction remains the same. This is consistent with the results in Fig. 7.

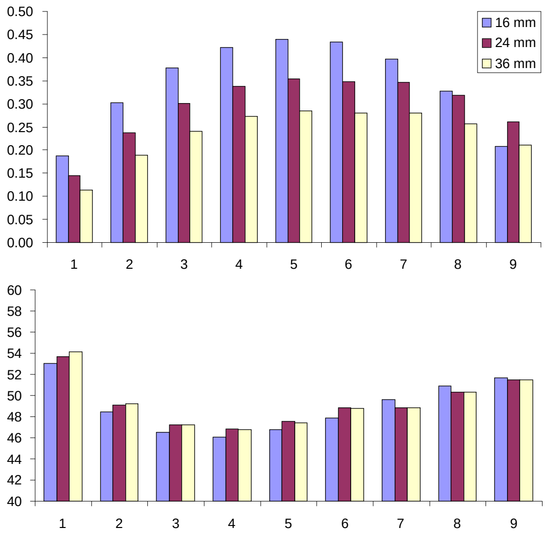

Fig. 8. The run-out of the cross sections of the 16, 24 and 36 mm white iron model, 1H-amplitude [mm] (above) and the phase [°] (below) at 125 °C surface temperature.

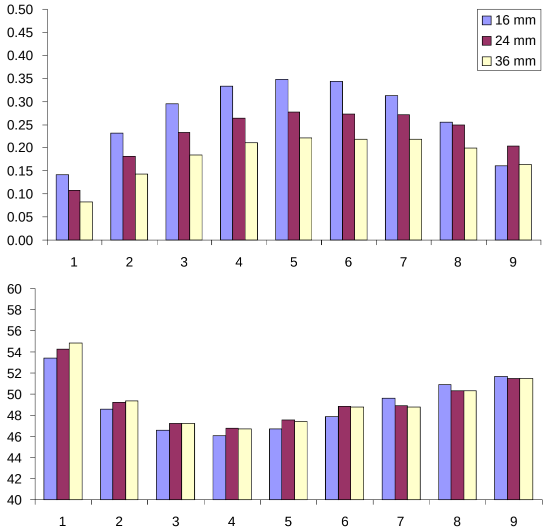

Fig. 9. The run-out of the cross sections of the 16, 24 and 36 mm white iron model, 1H-amplitude [mm] (above) and the phase [°] (below) at 150 °C surface temperature.

4. CONCLUSIONS

The results are consistent with previous studies and common knowledge about the behaviour of the chilled cast iron thermo rolls. To be able to validate the results from the FEM analyses there should be a run-out measurement from the test roll. There is a measurement result from the test roll made with heating oil temperature at 150 °C. The relation between the other measurement parameters and the boundary conditions of the FEM analysis is not known. Regardless of this the result is presented in Fig. 10.

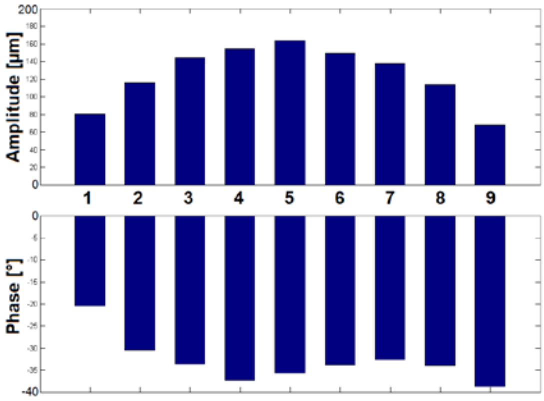

Fig. 10. Run-out measurement of the test roll in production conditions.

Even though the calculated results are not comparable with the actual measurement, they are discussed to some extent. The evident difference is in the amplitude. One obvious reason for this can be in the chosen material values. The material properties are chosen from different values found in the literature [6][8]. Also the boundary conditions of the FE model have strong effect on the run-out. Their effect and better alternatives should be studied further.

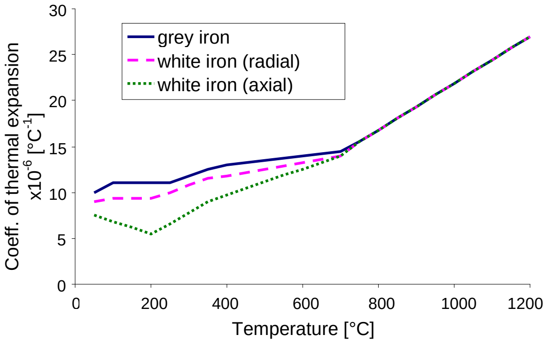

Fig. 11. Coefficients of the thermal expansion of the different iron phases in relation as a function of the temperature [3].

The temperature distribution in the model is simplified, thus very different from reality. In reality, the coefficient of thermal expansion is a function of temperature and

in white iron also a function of material direction (Fig. 11). In the FEM software the coefficient can be a function and this should be changed in the future models.
Temperature distribution of the test roll is also affected by the depth of heating oil passages in the roll body. The heat transfer from passages closer to surface is more effective. The bore depths of the passages were also measured during the tests and the results are presented in Fig. 12. In the middle of the roll the depth variation is more than 15 mm. This can cause an uneven temperature distribution in the roll body which can affect the deflection and its direction. The modelling of this phenomenon is probably very challenging.

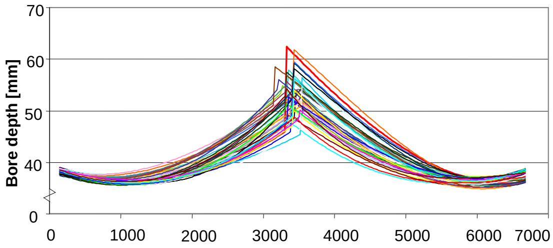

Fig. 12. Heating oil passage bore depths in the test roll body. The test roll has 40 bores.

The thermal deflection causes an unbalance in the roll. If the roll rotates (as during the run-out measurements), this will increase the run-out because of the unbalance. If the rotation is implemented in the FE models, the calculated amplitude will increase even more.
To validate the results from FEM analysis, the test roll run-out measurements and the ultrasonic measurements should be repeated under controlled circumstances. The exact material properties in the roll should also be measured. Normally, this cannot be done in a production roll, because the dismantling of the roll is not allowed. The co-operation with the roll manufacturer can provide a solution to this problem.
In its present form the developed method can produce useful information about the thermo rolls, but if it is enhanced with the proposed corrections it will become an even better tool.

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