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A NUMERICAL INVESTIGATION OF THE EFFECT OF ALUMINUM SHEET THICKNESS ON WOUND ROLL STRESSES

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INTRODUCTION

A unique combination of physical properties of aluminum is used in flexible packaging as well as in automotive heat exchangers. Depending on the end usage, aluminum foils are produced with various thicknesses, which affect wound roll stresses. In this study, residual stresses in wound roll for two foil thicknesses and various anisotropy ratios were studied numerically using finite element method.

METHODS

Material and Thickness of Foils

Two various foils were involved in the present study: the thinner foil for packaging of chocolate with thickness 0.010 mm and the foil for lids (0.035 mm). Prior to winding, both foils were only cold rolled. Heat and other finish treatments were processed afterwards. Table 1 summarizes types of both materials, their thicknesses and material properties.

Table 1. Material, thickness and effective radial moduli of studied foils

Usage	Material pursuant to EN 573-3	Material type	Thickness [mm]	Bulk modulus E [MPa]	Dependence of radial moduli E_r on interlayer pressure p $(= -\sigma_r)$ [MPa]
Packaging of chocolate	EN AW-8011	AlFeSi	0.010	70 000	$E_r = 68.66 \cdot (p + 1.012)$ for $p > 1.0$ $E_r = 140.0$ for $p \leq 1.0$
Lids	EN AW-8011	AlFeSi	0.035		$E_r = 259.3 \cdot (p - 0.346)$ for $p > 1.0$ $E_r = 170.0$ for $p \leq 1.0$

Numerical Model

The stresses inside wound rolls were determined using an accretive axi-symmetric finite element approach (Wimmer, 2008) and elastic transversely isotropic material characterization of an aluminum roll.

Whereas Young's moduli of the roll in circumferential and axial directions were the same as a bulk modulus, in radial direction the modulus E_r was measured by the compression of a stack of webs. Resulting effective value of E_r is pressure sensitive and encompasses the stiffness of sandwich structure composed from aluminum, air and oil layers as well as the effect of mutual contact of surface asperities. Measured relationships of E_r on interlayer pressure p are in Table 1.

A simulation sums up results from 100 single steps. The final rectangular mesh consists of 100 equal sized elements in radial direction. Each row of elements represents one added model layer with tens or hundreds of webs depending on the true foil thickness. 20 elements in axial direction are gradually refined from the center to coil side.

All main routines for model building and results evaluation were developed in Python scripting language, the finite element calculation in single simulation step were performed in CalculiX 2.10.

Coil Geometry and Winding Tension

To demonstrate the effect of foil thickness on residual stresses, all simulations have the same core and coil geometry and the same winding stresses. The inner and outer radius of the core was 72 and 75 mm respectively. The coil had a width 1000 mm and a diameter 600 mm. Winding tension was 30 MPa.

COMPUTED RESIDUAL STRESSES AND DISCUSSION

The axi-symmetric model allows computing stress variation along a radial as well as an axial direction of the coil. However, in this study, only stresses in the coil centerline are shown. Residual radial and hoop stresses for two studied foils after winding process are shown in Figure 1 and Figure 2 respectively, together with stresses for 4 fixed anisotropy ratios E_r/E ranging from 0.001 to 1 (isotropic material of coil).

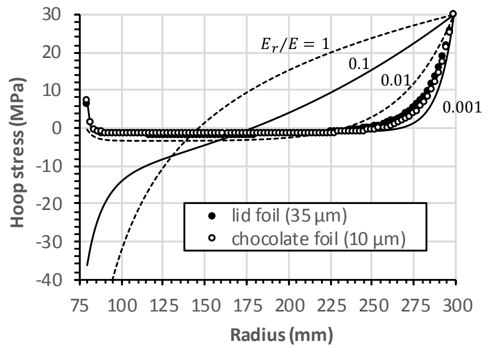

Figure 1. Effect of material anisotropy on residual hoop stress

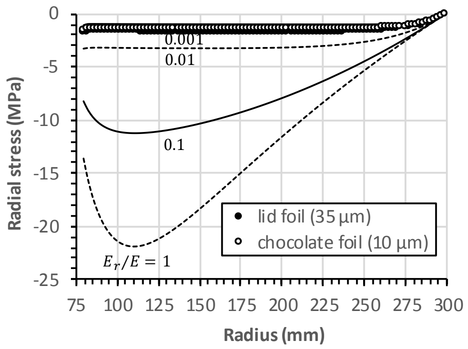

Figure 2. Effect of material anisotropy on residual radial stress

Contrary to fully isotropic or slightly anisotropic coil material with $E_r/E = 0.1$, both hoop and radial stresses for thin foils are negative and very low in almost 80 % of middle portion of the roll. The layers are stored under tension near the core and mainly in the outer portion, where peek hoop stress reaches the value of the winding tension. It is likely that further increase of foil thickness can lead to increase of anisotropy ratio, which causes increase of all residual stresses and change to tensile hoop stresses close to the core.

CONCLUSIONS

The pressure sensitive radial elastic modulus is slightly lower for the roll wound from aluminum foil with lower thickness, but for recommended value of wound-on-tension both moduli exhibit anisotropy ratios E_r/E lower than 0.01. Such values of anisotropy lead to vanishing of wound-roll stresses except the very small region close to core and outer of the roll.

ACKNOWLEDGMENT

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REFERENCES

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KEYWORDS

Aluminium foil, Foil thickness, Wound-roll stresses, FEM model

A Numerical Investigation of the Effect of Aluminium Sheet Thickness on Wound Roll Stresses

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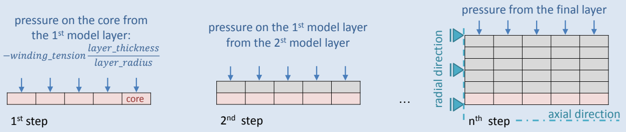
Depending on the end usage, aluminium foils are produced with various thicknesses, which affect wound roll stresses.

Main objective was to evaluate residual stresses in wound roll for two foil thicknesses and four anisotropy ratios using finite element method.

Numerical model

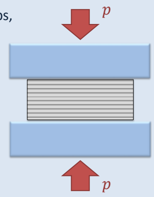
- Elastic transversely isotropic material characterization of the roll (softer in radial direction),
- accretive axi-symmetric finite element approach (final stresses summed up from all modelling steps),
- cylindrical shape of the roll (outer radius is kept uniform along the axial direction).



Determination of radial modulus E_r

- Compression of a stack of webs,
- Pfeiffer's equation with threshold at pressure 1 MPa.

$$E_r = K_2(p + K_1)$$



Foil material and thickness

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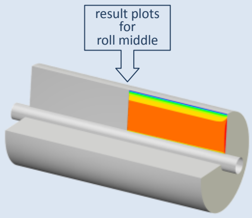
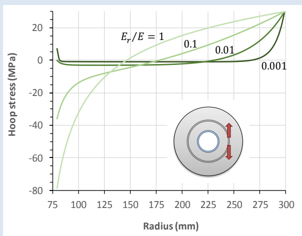
Wound-roll stresses

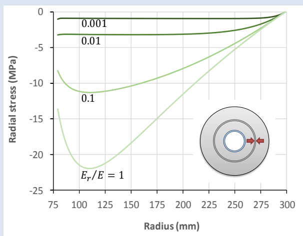


Circumferential (hoop) stresses

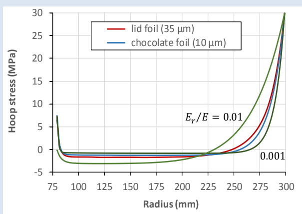
Radial stresses

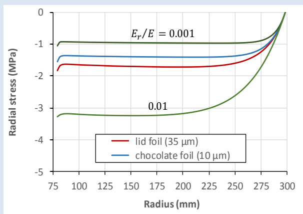
For constant anisotropy E_r/E





For pressure dependent anisotropy measured on foils





Conclusions

- The pressure sensitive radial elastic modulus is slightly lower for the roll wound from aluminium foil with lower thickness.
- For recommended value of wound-on-tension both moduli exhibit anisotropy ratios E_r/E lower than 0.01.
- Such values of anisotropy lead to vanishing of wound-roll stresses except the very small region close to core and outer of the roll.