Coupling procedure of a cold rolling lubrication model with finite element simulation of asperity flattening

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ABSTRACT

Reducing the thickness of increasingly resistant, wider and thinner metal strips by cold rolling requires a strict friction control to maximize the throughput while preventing chattering. In the mixed lubrication regime, friction is the result of interacting solid asperity tops of rough surfaces, i.e. those of the roll and the strip, in the presence of a lubricant, which partially supports the load.

In the past, the METALUB model was developed to predict the rolling load and forward slip, which are representative of the friction state in cold rolling. This model is based on the slab method, the average Reynolds equation with flow factors, an adiabatic thermal model, various thermoviscoplastic strip and thermopiezoviscous lubricant material laws, elastic roll deformation methods and the analytical asperity flattening law by Wilson & Sheu [1]. This law describes the growth of solid/solid contact between the roll and the strip, and thus friction, with rising bulk strain due to the elongation of the material in the bite, increasing pressure on the asperity tops or decreasing lubricant pressure in the valleys. Since the law was derived by the upper-bound method for a simplified geometry, elastic deformations are neglected, the result is not the exact theoretical solution but an overestimation of the solid/solid contact area, and the law does not take a realistic representation of the asperity geometry into account.

To alleviate these shortcomings, a coupling procedure between METALUB and our in-house finite element (FE) solver for large deformations, METAFOR, was created. This procedure starts by METALUB computing the strip elongation, the lubricant pressure and the interface pressure, which is the resulting average pressure of the asperities and the lubricant on the strip, along the roll bite with the classical law by Wilson & Sheu. Based on these values, a FE METAFOR simulation of the asperity flattening then computes the resulting solid/solid contact area and the lubricant film thickness, which can be used in a subsequent METALUB computation instead of the prediction by Wilson & Sheu. The elastoplastic FE model is particularly original since the flattening process is described in the extended plane strain state, i.e. that a strip portion with an arbitrary roughness profile, like the rigid roll portion, is modeled in the plane which is perpendicular to the rolling direction. In this plane, the expansion of the strip portion in the lateral directions is prevented due to the classical plane strain hypothesis in cold rolling, while its out-of-plane elongation is imposed by the METALUB result. The lubricant pressure is then imposed on its top, where it is not in contact with the roll, and the interface pressure pushes the portion against to roll by the application of this pressure on the lower edge. Hence, the previous shortcomings of the asperity flattening law by Wilson & Sheu were essentially removed from the cold rolling model by this coupling procedure. Furthermore, the numerical results were validated by experimental measurements of a semi-industrial pilot mill.

REFERENCES

[1] W. R. D. Wilson and S. Sheu (1988), *Real area of contact and boundary friction in metal forming*, Int. J. Mech. Sci., Vol. 30(7), pp. 475 - 489.