Accurate Strain Field Measurement during Strip Rolling by exploiting Recurring Material Motion in Integrated Digital Image Correlation

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Abstract

A novel (updated) Integrated Digital Image Correlation (IDIC) framework is proposed that fully exploits the notion of continuous, recurring material motion during strip rolling in order to robustly yield high-quality velocity fields and strain fields of the steel strip while it is being plastically deformed by the rolls under harsh circumstances for in-situ optical imaging. Based on first results of two very different, successfully executed strip rolling experiments (operated at various settings), it may already be concluded that this novel IDIC framework yields highly robust image correlation convergence, thus providing the exciting prospective that, for the first time, the deformation fields of the strip between the rolls can be measured with high accuracy. This may open the door to unravel subtle changes in the deformation and strain fields due to variations in pre-deformation, elastic recovery, and geometrical irregularities, which may allow to optimize roll operating settings with much higher precision.

Keywords: Integrated Digital Image Correlation, Strip rolling, Strain field, velocity field

Introduction

95% of non-ferrous/ferrous metals and alloys are processed by means of strip rolling, making it the most important metal forming process. In strip rolling, generally a multi-pass system is employed to achieve a huge thickness reduction. Over the years, various models have being developed to optimize the multi-pass deformation process. To push these models to the next level, direct accurate in-situ measurement of the full deformation and strain fields of the (steel) strip between the rolls is required. Efforts in this direction were, so far, seriously hampered by (i) the harsh environment (oil contamination, vibrations), (ii) challenging imaging conditions (obstructed field of view between the rolls, limited viewing angle along the strip, limitations in lighting), (iii) the high material velocity, requiring a short shutter time at the expense of large acquisition noise, and (iv) unavoidable light reflections combined with a non-ideal DIC speckle pattern. Therefore, standard (local) DIC algorithms fail at this task.

Research goals

To address these challenges, a novel (updated) Integrated Digital Image Correlation (IDIC) framework is proposed that fully exploits the notion of continuous, recurring material motion during strip rolling in order to robustly yield high-quality velocity fields and strain fields of the steel strip between the rolls.

Strategy

High robustness against light reflections and missing speckles as well as high strain accuracy is achieved by the following two steps:

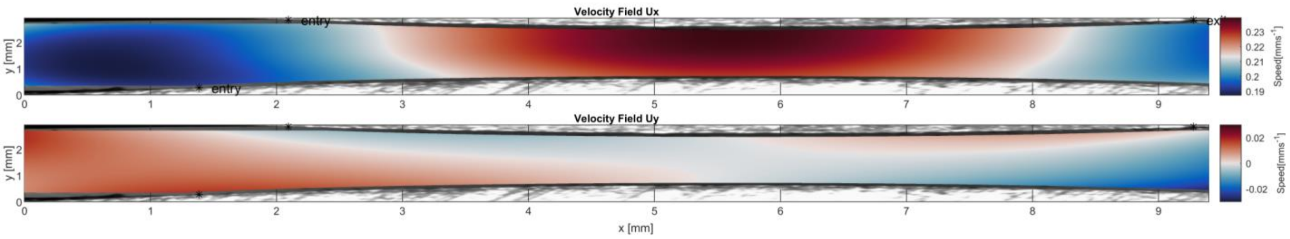
1. Many (e.g. 200) image pairs are simultaneously correlated, each correlated with the same average global displacement field (described by a single set of spatial degrees of freedom) but multiplied with a separate *velocity multiplicator* to account for (slight) differences in material velocity between image pairs.
2. Following [1], the IDIC framework has been derived in a consistent mathematical setting, by minimizing the non-linear brightness conservation equation through a one-step linearization to obtain the true DIC tangent operator and correct image gradient, to further increase correlation robustness.

To validate the potential of this new IDIC framework, two different rolling experiments have been performed by strip rolling (a) a sheet of rubber in a Hand Mill and (b) a steel strip on the Pilot Mill of Tata Steel.

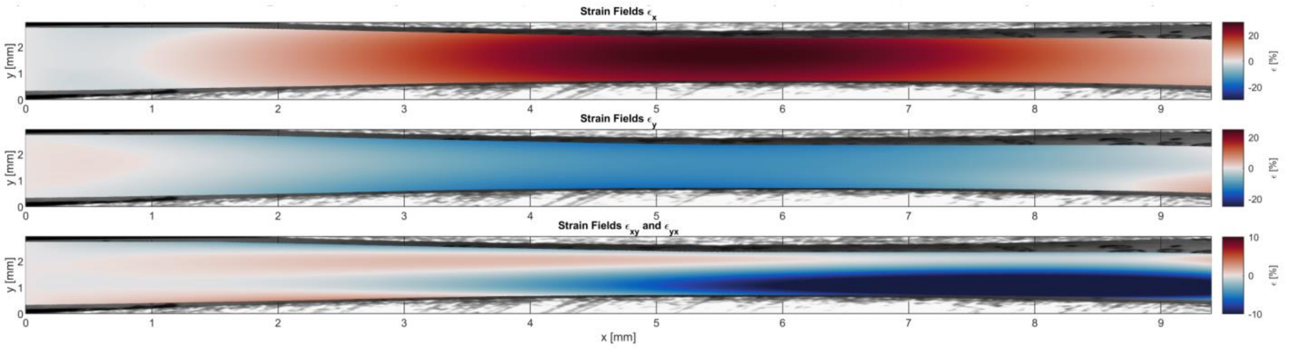
Preliminairy results

The order of the polynomial basis used in the description of the displacement field has been tested and optimized. It was found that the kinematic freedom of a fourth order polynomial is sufficiently rich to accurately describe the occurring displacement field between the rolls, while the low amount of degrees of freedom (dofs) is a crucial element to increase the robustness of the correlation.

Next, the effect is tested of taking more and more images, up to 150 (!) images, on board in the correlation, i.e. the full region of image of all images are correlation all at the same time using a single (4th order polynomial) displacement field. As can be seen in Fig. 2, for increasing amount of images that are simultaneously correlated, the spread in the dofs describing the displacement field quickly decreases, showing that the correlation robustness becomes increasingly robust by adding more and more image to the correlation.
An example of a preliminary results of the Hand Mill are shown in Fig. 1. The figure nicely shows that both the velocity field in x and y direction can be obtained from the obtained displacement field as well as the in-plane strain fields (in this case the fields of the ε_{xx}, ε_{yy}, and ε_{xy} components of the Green-Lagrange strain tensor). Note that these results are preliminary as the analysis is still being further optimized, however, it was already observed that the accuracy of the in-situ velocity and strain fields under strip rolling appears to be much higher than other methods presented in the literature so far.



(a) *Velocity fields*



(b) *Strain fields*

Figure 1: *Robustly converged results for the Hand Mill case, with in (a) the velocity field in x and y direction and (b) the fields of the εxx, εyy, and εxy components of the Green-Langrange strain tensor). Note that these results are preliminary as the analysis is still being further optimized.*

Successful measurements of the velocity and strain field, similar to Fig. 3 have been made both on the Hand Mill and on the Tata Steel Pilot Mill (not shown here) for various settings of the strip tension and roll pressure. The analysis of these results is still ongoing, but it was already observed that it is possible with this method to unravel subtle changes in the deformation and strain fields due to variations in pre-deformation, elastic recovery, and geometrical irregularities. The final results will be published elsewhere.

Conclusions

Based on these preliminary results, it can already be concluded that the potential of the IDIC framework for recurring material motion seems to have been successfully demonstrated on two very different in-situ strip rolling experiments (operated at various settings), showing robust convergence of the simultaneous correlation of a large set of images and yielding high accuracy in the velocity and strain fields. The method provides an exciting prospective for unraveling subtle changes in the deformation and strain fields due to variations in pre-deformation, elastic recovery, and geometrical irregularities.

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References

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