# 1.3 Simulation of springback: adaptive quadrature

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## Introduction

Error due to the numerical integration in thickness direction is yet another reason of common inaccuracy of springback prediction. Traditional schemes may require up to 50 integration points for reliable results of springback analysis. However, in simulations of sheet metal forming (Figure 1), increasing the number of integration points places high demands on computational costs and is very undesirable.

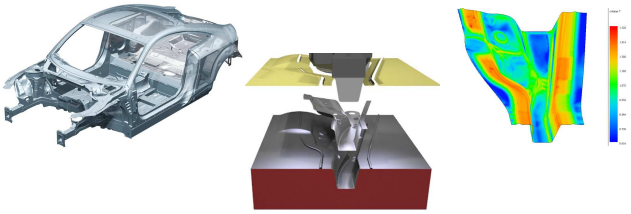

*Figure 1: Simulation of sheet metal forming.*

## Objective

Develop a strategy for adaptive through-thickness integration that can guarantee the accurate solution while using a limited number of integration points.

## Results

The developed adaptive strategy includes several algorithms that perform additional tasks during a simulation, i.e locate elastic-plastic transitions; adapt the position of integration points; update their internal variables and perform the actual integration [1]. Performance of the adaptive quadrature is evaluated using the NUMISHEET'02 benchmark (Figure 2).

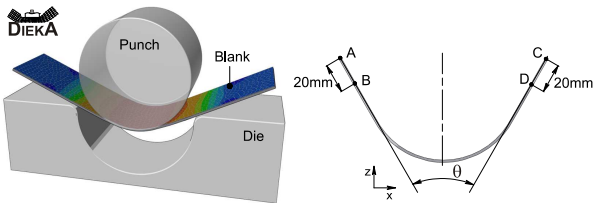


*Figure 2: Unconstrained cylindrical bending.*

**Relative error.** Simulations of this test show that the traditional integration rules may require about 20 integration points to minimise the numerical integration error (Figure 3). To achieve similar accuracy, the adaptive scheme uses twice as less integration points.

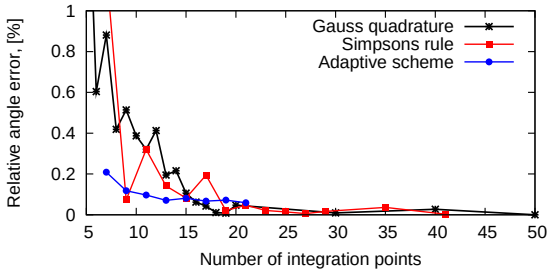


*Figure 3: Error in predicting angle $\theta$ after springback.*

In contrast to the traditional schemes, the accuracy of the adaptive quadrature is not influenced by changes in material or process parameters (Figure 4).

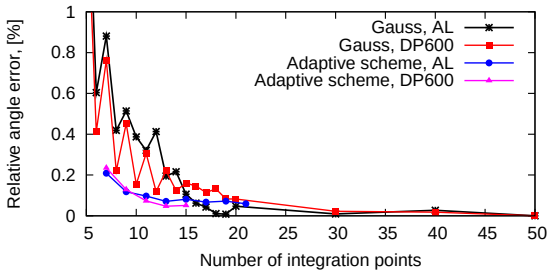


*Figure 4: Results of simulations with different materials.*

**CPU time.** Significant savings in computation time can be obtained by using the available integration points more efficiently (Figure 5).

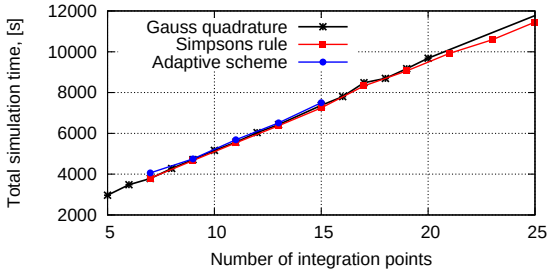


*Figure 5: CPU time versus the number of integration points.*

## Future work & Valorisation

Some modifications are needed to make the adaptive strategy suitable for simulations of industrial products.

## References

[1] I.A.Burchitz and T.Meinders. Adaptive through-thickness integration for accurate springback prediction, accepted for publication at IJNME.

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