

Experience from using recently implemented enhancements for Material 36 in LS-DYNA 971 performing a virtual tensile test

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ABSTRACT:

In today's automotive industry the development of car bodies considerably depends on the use of computer-aided tools to meet the challenges of rising product complexity and growing number of variants.

Today, enabled by modern simulation software, improved material models and numerical methods, simulation has become essential for the evaluation of sheet-metal-stamping processes before press tools are manufactured. Though modern material models are available, some effects are not described correctly, because some parameters are assumed to be constant. In reality, a lot of these "constant" values must be considered variable. To better represent the real material behaviour, some enhancements for the standard material models have to be implemented to get a more realistic simulation.

In this paper we present the results of virtual tensile tests, comparing input- and output-parameters, using the first LS-DYNA material model with variable Lankford coefficients / R-values, yield curves, volume and Young's modulus. All these features are now available in one material model – LS-DYNA 971 Material 36.

KEYWORDS:

Material model, LS-DYNA 971, Material 36, R-Values, Young's modulus

INTRODUCTION

Nowadays there are numerous requirements for the development of new cars. Especially for the production of single car body parts, innovative design with complex geometries, increasing product functionality, variety of variants, reduction of car body weight, innovative materials and production techniques, shortening of tool development times and cost reduction in general are essential demands.

To satisfy all requirements, modern simulation software is used during the development to simulate the sheet-metal-stamping process, before the stamping tools are manufactured. In a sheet-metal-stamping simulation, the material behaviour is described by using material models, such as Hill'48 or Barlat'89 [2], [3].

Current models are based on assumptions like constant parameters in order to reduce its complexity. Consequently the real material behaviour is not described exactly.

Hence, in current material models, only a few input-parameters are necessary for the mathematical description of the material behaviour. In the material models Hill'48 and Barlat'89, these input-parameters are:

- One constant Young's modulus – E .
- Three constant Lankford coefficients / R-values – R_{00} , R_{45} and R_{90} .
- One yield curve – $k_f(\varphi_{plast})$.

REQUIREMENTS

Recently it has been proven that the Young's modulus is not constant, but strain dependent [5]. The R-values are not constant either; but also strain-dependent [4]. For new materials like TRIP-steels, the assumption of a constant volume during the forming is not correct, because there is a change in the microstructure.

To get a more realistic mathematical description of the real material behaviour, we present a material model with the following enhancements:

- Variable R-values.
- Variable Young's modulus.
- Variable volume.
- Three independent yield curves for 00°, 45° and 90° rolling direction.

Further, with virtual tensile tests we examine whether the material input-parameters are reproduced exactly by the mathematical description.

IMPLEMENTATION OF THE ENHANCEMENTS FOR THE MATERIAL MODEL IN LS-DYNA 971 IN MATERIAL 36

T. Borrvall [8] integrated the following enhancements into LS-DYNA 971 Material 36 [1], to get a more realistic mathematical description of the material behaviour:

- $R_{XX} = R_{XX}(\varphi_{plast})$; XX for 00°, 45° and 90° (Eq. 1)

- $E = E(\varphi_{plast})$ (Eq. 2)

- $V = V(\varphi_{plast})$ (Eq. 3)

- $k_{f_XX} = k_{f_XX}(\varphi_{plast})$; XX for 00°, 45° and 90° (Eq. 4)

VIRTUAL TENSILE TEST WITH LS-DYNA 971 IMPLICIT

The tensile test is described in *DIN EN 10002* [7] and the geometry of the specimen is defined in *DIN50125* [6]. Based on the real tensile test, virtual tensile tests are used to analyse the quality of the new enhancements in a virtual test loop. In this virtual test loop, input- and output-parameters are compared, see Figure 1.

The virtual tensile test also uses a test specimen, see Figure 2, and the following parameters are determined:

- Resulting forces F .
- Change in length ΔL .
- Change in width ΔB .

With these determined parameters, the output-parameters yield curve, R-value and Young's modulus from the virtual tensile test specimen are calculated.

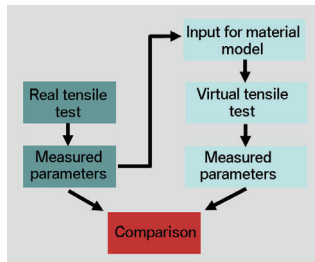


Figure 1: Virtual test loop for comparison of input- and output-parameters

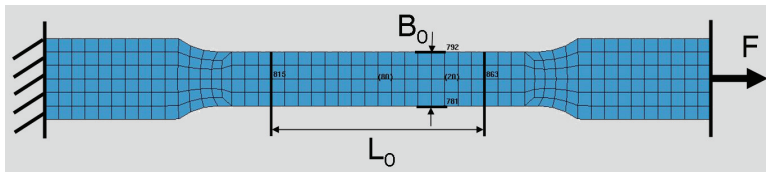


Figure 2: Virtual tensile test specimen with defined measurement

MATERIAL INPUT-DATA FOR THE VIRTUAL TENSILE TEST

According to standard deep drawing steel, the following input-parameters were chosen for the virtual test-material:

- $R_{00} = 1.7$, $R_{45} = 1.3$ and $R_{90} = 1.9$.
- $E_0 = 210000 \text{ N/mm}^2$.
- One standard yield curve, see Figure 3.

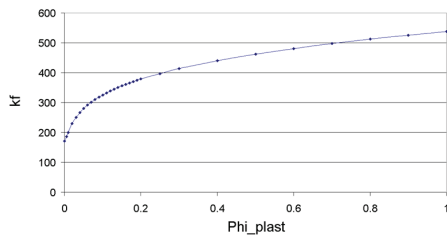


Figure 3: Yield curve for 00° rolling direction

To test the recently implemented enhancements, the following parameters are assumed for the test-material. None of the following values have been measured.

- Three different yield curves (Figure 4) – 00° yield curve (Figure 4) is multiplied with the factor 1.1 for 45° yield curve and multiplied with the factor 1.2 for 90° yield curve.
- Three variable R-values (Figure 5) – functions for R_{00} , R_{45} and R_{90} starting at $R_{XX} = 1$ and stabilizing at $\varphi_{plast} = 0.1$ to $R_{00} = 1.7$, $R_{45} = 1.3$ and $R_{90} = 1.9$.

- Change in volume (Figure 6):
$$V_{rel} = 1 - a \cdot (e^{\varphi_{plast}} - 1) \quad (\text{Eq. 5})$$

with $a = 0.3$.

- Change in Young's modulus (Figure 7) [1], [5]:

$$E = E_0 - (E_0 - E_A)(1 - e^{-a \cdot \varphi_{plast}}) \quad (\text{Eq. 6})$$

with $E_0 = 210000 \text{ N/mm}^2$, $E_A = 180000 \text{ N/mm}^2$ and $a = 10$.

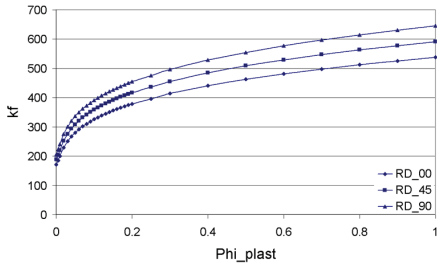


Figure 4: Yield curves for 00°, 45° and 90°

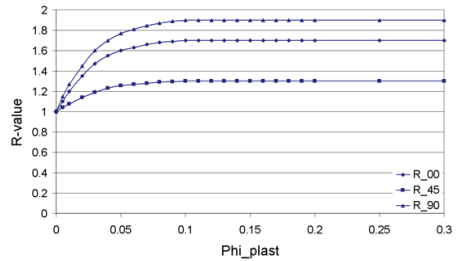


Figure 5: R-Values for 00°, 45° and 90°

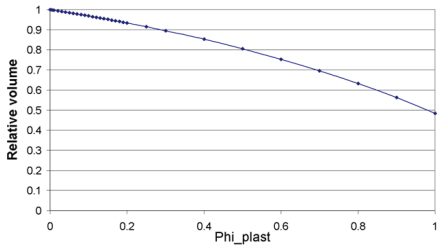


Figure 6: Volume correction curve

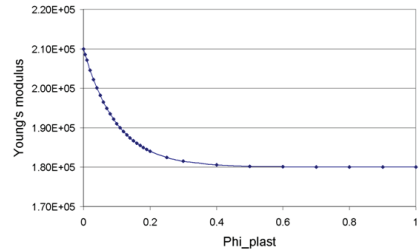


Figure 7: Variable Young's modulus

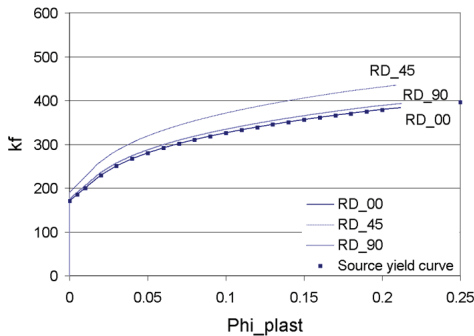
RESULTS OF THE VIRTUAL TENSILE TEST

Virtual tensile tests are used to analyse the quality of the new enhancements in a virtual test loop, see Figure 1. Five different virtual tests are performed to describe the behaviour of a standard material model and to propose the new possibilities to define the material behaviour numerically. The following test-settings are used:

- Test 1: Standard Barlat'89 material model with varying M -parameter.
- Test 2: Three identical and three different yield curves with constant R -values.
- Test 3: Three different yield curves and three variable R -values.
- Test 4: Standard Barlat'89 material model with volume correction.
- Test 5: Standard Barlat'89 material model with variable Young's modulus.

TEST 1: RESULTS FROM VIRTUAL TENSILE TEST USING STANDARD MATERIAL 36 - BARLAT'89 - WITH VARYING M -PARAMETER

Based on the virtual tensile tests in 00° , 45° and 90° rolling direction using a standard Barlat'89 material model (input-parameters: one yield curve and three constant R -values) with varying M -parameter, the resulting output-parameters yield curves, see Figure 8, and R -values, see Table 1 are presented.



	Input	$M = 2$	$M = 4$	$M = 6$	$M = 8$
R_00	1.7	1.71	1.72	1.75	1.78
R_45	1.3	1.31	1.31	1.33	1.35
R_90	1.9	1.92	1.93	1.96	2.00

Figure 8: Input- and output- yield curves from virtual tensile test for 00° , 45° and 90°

Table 1: Input- and output- R -values from virtual tensile test – M -dependent

The yield curve for the 00° direction is reproduced well. The problem with the resulting yield curves for 45° and 90° is that they are scaled by the R-values, because they are not independent from each other. In addition resulting R-values are *M*-dependent. see [2].

With standard material models, material behaviour of materials with nearly identical or absolutely not identical yield curves in 00°, 45° and 90° direction and different R-values can not be described exactly.

TEST 2: RESULTS FROM VIRTUAL TENSILE TEST USING THREE IDENTICAL AND THREE DIFFERENT YIELD CURVES

For the second test, three identical, see Figure 3 and three different, see Figure 4 yield curves for the rolling directions 00°, 45° and 90° are used. Figure 9 and Table 2 show the input- and output- yield curves and R-values from the virtual tensile test using three identical yield curves. Figure 10 and Table 3 show the input- and output- yield curves and R-values from the virtual tensile test using three different yield curves.

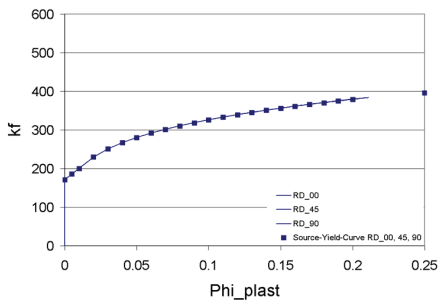


Figure 9: Input- and output- yield curves from virtual tensile test using three identical yield curves

	Input	Output
R_00	1.7	1.71
R_45	1.3	1.30
R_90	1.9	1.90

Table 2: Input- and output- R-values from virtual tensile test using three identical yield curves

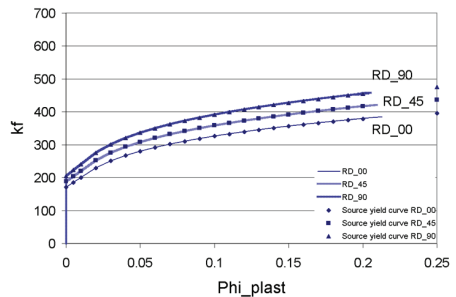


Figure 10: Input- and output- yield curves from virtual tensile test using three different yield curves

	Input	Output
R_00	1.7	1.72
R_45	1.3	1.32
R_90	1.9	1.92

Table 3: Input- and output- R-values from virtual tensile test using three different yield curves

In this test the input-parameters match well with the output-parameters. In both cases - three identical and three different yield curves - the input-parameters for yield curves

and R-values are reproduced very well. With the option of defining three yield curves, it is possible to define three yield curves that will be reproduced exactly in the virtual tensile test, because R-values and yield curves are independent here.

TEST 3: RESULTS FROM VIRTUAL TENSILE TEST USING THREE DIFFERENT YIELD CURVES AND THREE VARIABLE R-VALUES

In the third test, three different yield curves for the rolling directions 00°, 45° and 90°, see Figure 4, and three varying R-values, see Figure 5, are used.

Because of the independency of yield curves and R-values in this test, the yield curves are reproduced exactly as in the second test, see Figure 11. Figure 12 shows the variable input- and output- R-values for this test.

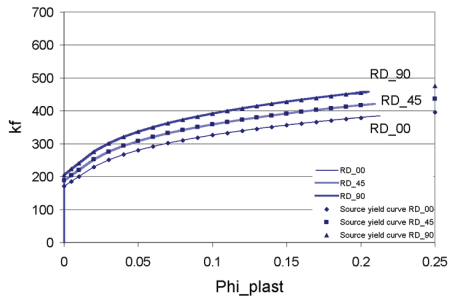


Figure 11: Input- and output- yield curves from virtual tensile test using three different yield

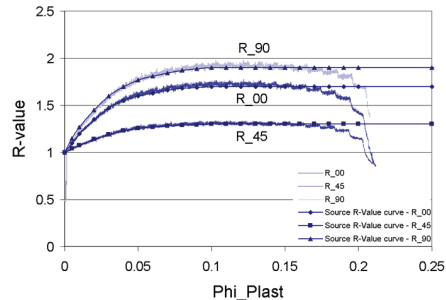


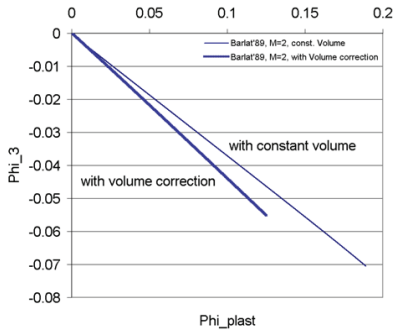
Figure 12: Variable input- and output- R-values from virtual tensile test using three different yield

The variable R-values are reproduced very well. The R-values start decreasing at $\varphi_{plast} \approx 0.15$ because the specimen starts necking at this point. This test shows that yield curves and R-values can be defined independently with constant or varying R-values.

TEST 4: RESULTS FROM VIRTUAL TENSILE TEST USING VOLUME CORRECTION

In the fourth test, the standard input (one yield curve and three constant R-values) and a volume correction curve, see Figure 6, are used to show the effects of a volumetric change during the forming process. Figure 13 shows the dependency of φ_3 from the material model (Barlat'89 with $M = 2$) and the material behaviour in the specimen with

and without volume correction. Table 4 shows the input- and output- R-values for the test with and without volume correction.



	Input	Output - with volume correction	Output - without volume correction
R_00	1.7	1.66	1.71

Figure 13: Resulting φ_3 from virtual tensile with and without a volumetric change

Table 4: Input- and output- R_00 values with and without a volumetric change

With a standard material model (Barlat'89 with $M = 2$) φ_3 can be calculated with the assumption of a constant volume. But that is not correct for a material with a volumetric change. With the volume correction, a larger absolute value of φ_3 for the specimen is resulting for the tensile test. φ_3 is directly measured here. The input R_{00} value is reproduced well for the simulation with the volume correction, see Table 4.

TEST 5: RESULTS FROM VIRTUAL TENSILE TEST USING VARIABLE YOUNG'S MODULUS

In the fifth test, the standard input (one yield curve and three constant R-values) and a variable Young's modulus, see Figure 7, are used to show the effects of a strain dependent Young' modulus during the forming process.

Figure 14 shows a stretched specimen with plastic strain displayed. The simulation is stopped at certain stages to perform a springback-simulation. In each springback-simulation the actual Young's modulus is calculated from change in length ΔL and actual stress.



Figure 14: Stretched specimen from virtual tensile test – plastic strain value displayed

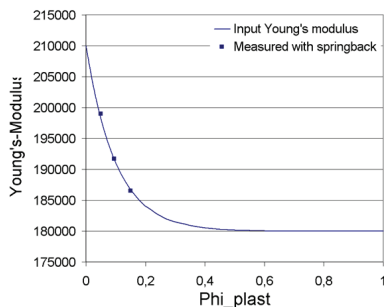


Figure 15: Input- and output- Young's modulus

Figure 15 shows the changing input Young's modulus and the resulting Young's modulus from the springback-simulations. The input values are reproduced exactly.

SUMMARY AND CONCLUSIONS

In this paper we presented a virtual tensile test using some modifications and enhancements for a standard material model. In contrast to the implemented standard material models in LS-DYNA 971, we use more variable parameters to describe the material behaviour of a virtual test-material. We showed that the new implementations, – variable R-values, variable Young's modulus, variable volume and yield description with 3 independent yield curves – numerically worked well for the virtual tensile test and are able to reproduce the input-parameters very well. This gives the user more possibilities to model the material behaviour with one material model.

The material model worked fine on a virtual tensile test. Future work includes some other easy tests and a real deep drawing part.

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