Metal Tensile Test Using Miniaturized Test Pieces

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Objective

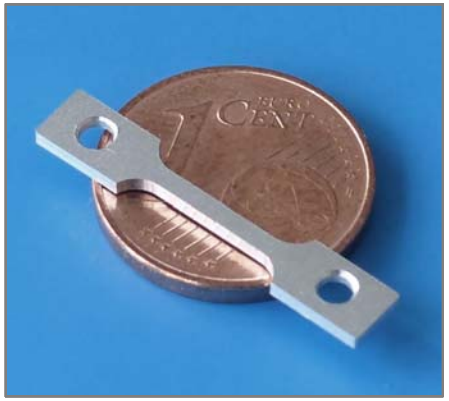
Development and Optimisation of the testing technique for testing of miniaturised test tensile test pieces for the determination of local strength properties and flow curves from deformed component areas for e. g. the following applications:

- Verification of component specifications and optimisation of the production of components
- Validation of FE-forming simulations
- Determination of input data for crash and service life calculation
- Characterisation of local properties of weldings
- Evaluation of cases of damage

Problem definition and boundary conditions

Problem definition

- Clamping of the test piece without bending and shearing forces
- Warranty of uniaxial stress
- Dimensionally accurate machining of the test pieces without workhardening and heat input
- Realisation of small gauge length and accurate measurement of very small extensions



- Largely compliance of normative specifications acc. to ISO 6892-1:2009

Boundary conditions

- Applicable in the normal industrial environment, this means by using mainly standard equipment
- Largely comparability with standard tensile test properties

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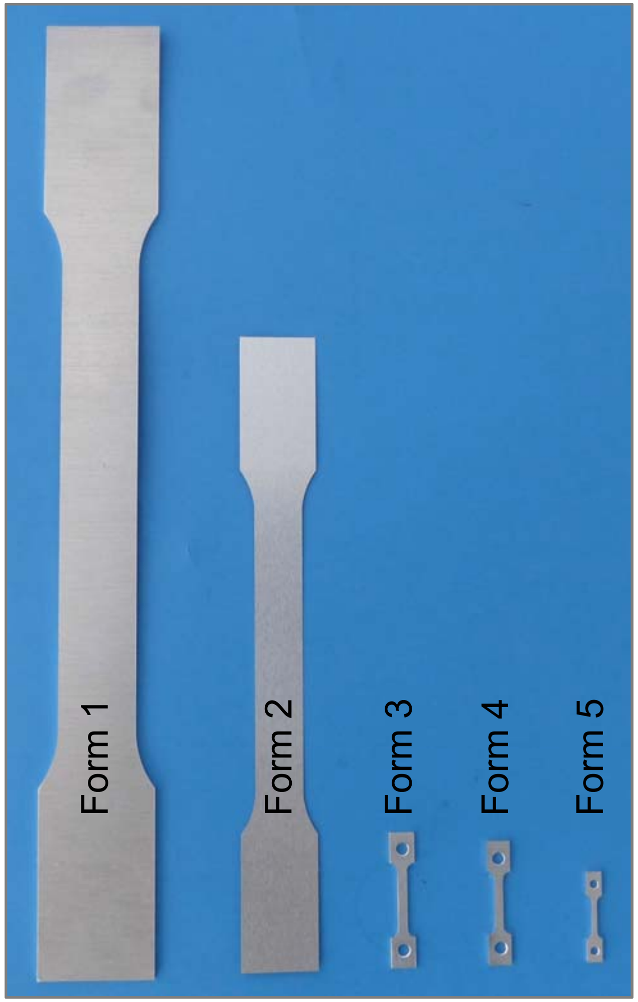
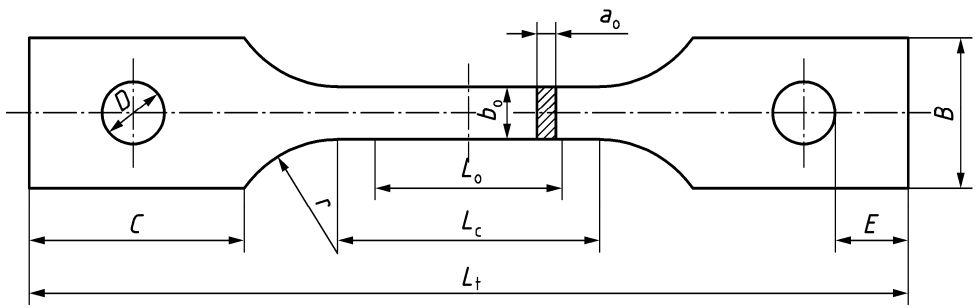
Investigated test piece geometries



Form	L_t (mm)	B (mm)	b_o (mm)	L_c (mm)	L_e (mm)	C (mm)	D (mm)	E (mm)	r (mm)	$\frac{L_c}{b_o}$	$\frac{L_e}{b_o}$
Form 1	250	30	20	120	80	35	-	-	20	6	4
Form 2	165	20	12.5	75	50	30	-	-	20	6	4
Form 3	35	6.5	2.5	15	10	8	3	3	2	6	4
Form 4	32	6.0	2.0	12	10	8	3	3	2	6	5
Form 5	23	4.0	1.25	7.5	5	6	2	2	2	6	4

L_e = Extensometer gauge length



Source: ISO 6892-2:2011-02

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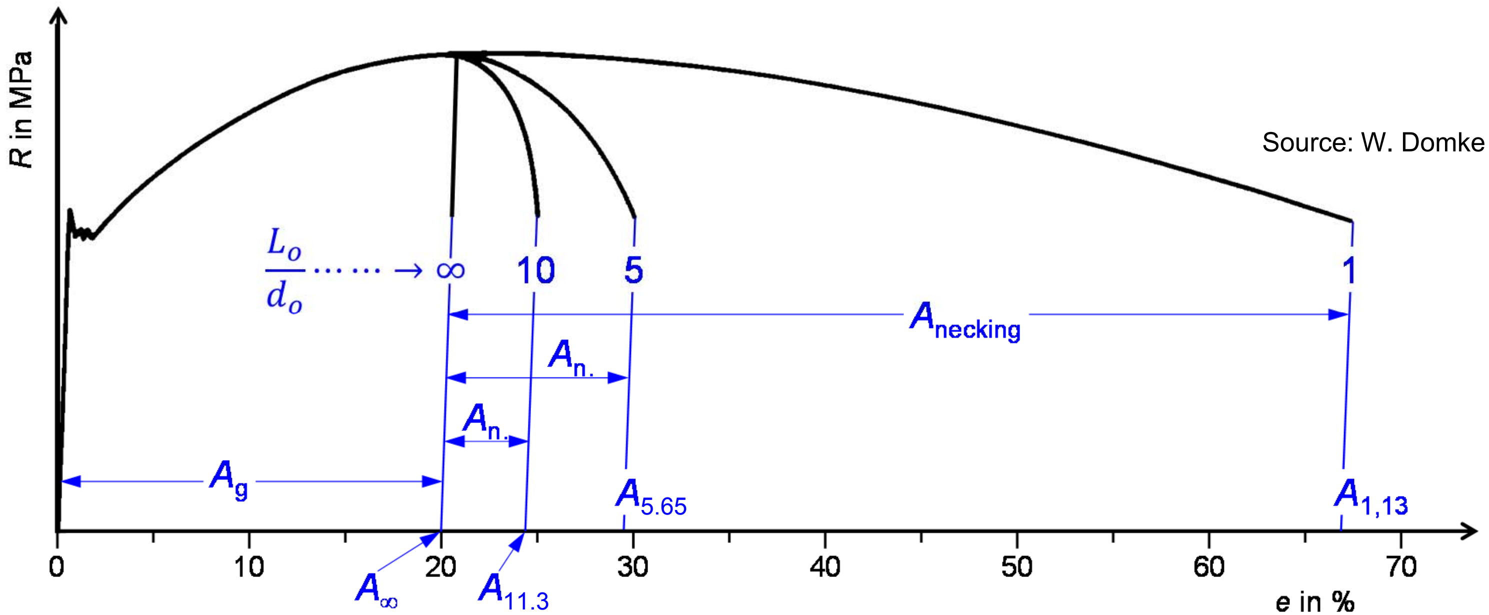
Influence of the gauge length on elongation after fracture



Nearly equal elongations after fracture for different test piece geometries only if:

- Equal coefficient of proportionality *k* of the test pieces (Standard: 5.65)

Non proportional test pieces (A_{50mm}, A_{80mm}): Nearly equal thicknesses are necessary.

"Comparisons of percentage elongation are possible only when the gauge length or extensometer gauge length, the shape and area of the cross-section are the same or when the coefficient of proportionality, k, is the same." (ISO 6892-1:2009)

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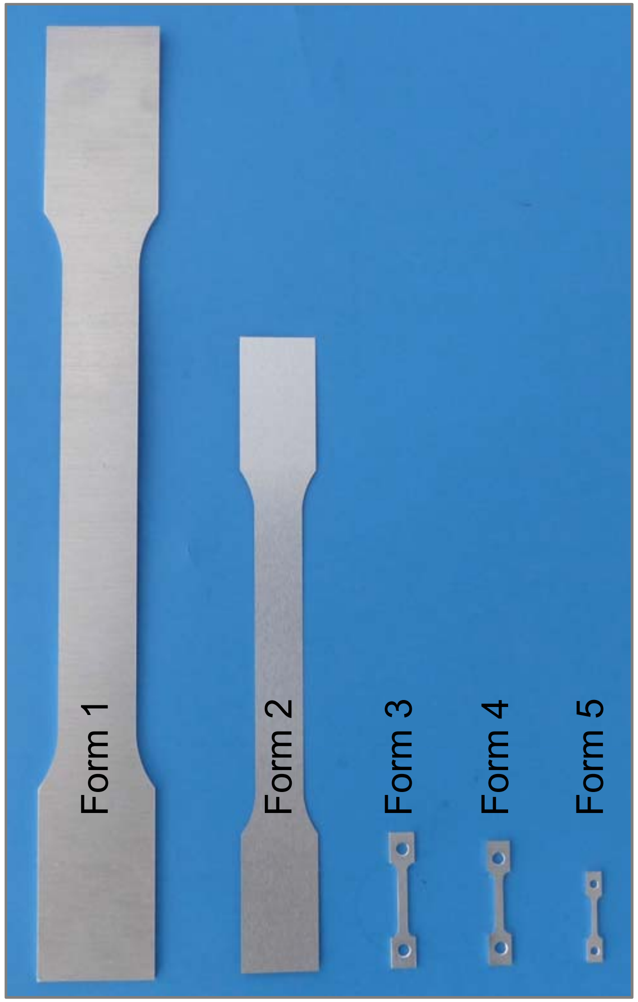
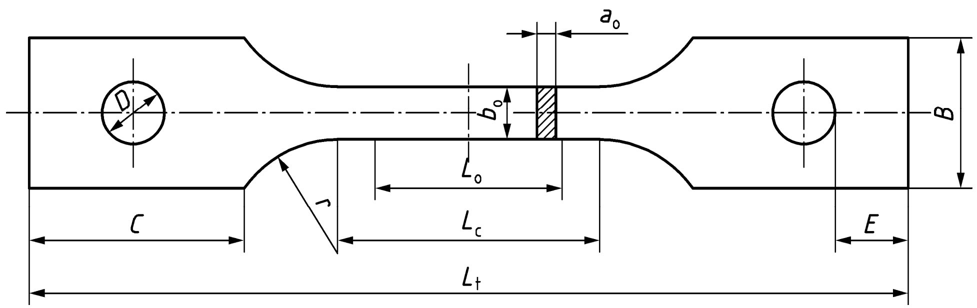
Coefficient of proportionality of the investigated test piece geometries



Form	L_t	B	b_o	L_c	L_e	r	$\frac{L_c}{b_o}$	$\frac{L_e}{b_o}$	$k_{1,0}$ mm	$k_{0,29}$ mm
Form 1	250	30	20	120	80	20	6	4	17.89	33.22
Form 2	165	20	12.5	75	50	20	6	4	14.14	26.26
Form 3	35	6.5	2.5	15	10	2	6	4	6.32	11.74
Form 4	32	6.0	2.0	12	10	2	6	5	7.07	13.13
Form 5	23	4.0	1.25	7.5	5	2	6	4	4.47	8.30

L_e = Extensometer gauge length



Source: ISO 6892-2:2011-02

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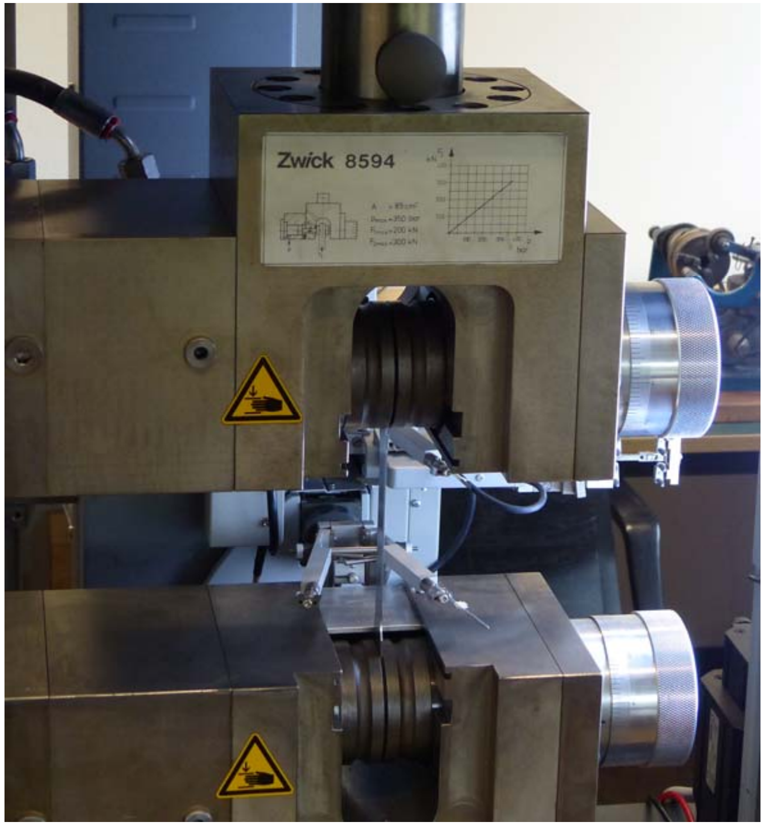
Testing machine, clamping system and force measurement



- 250 kN load cell
- Hydraulic clamping system
- Extensometer class 0.5

- 2.5 kN load cell
- Bending and shear force free clamping by using bolts
- Extensometer class 0.5

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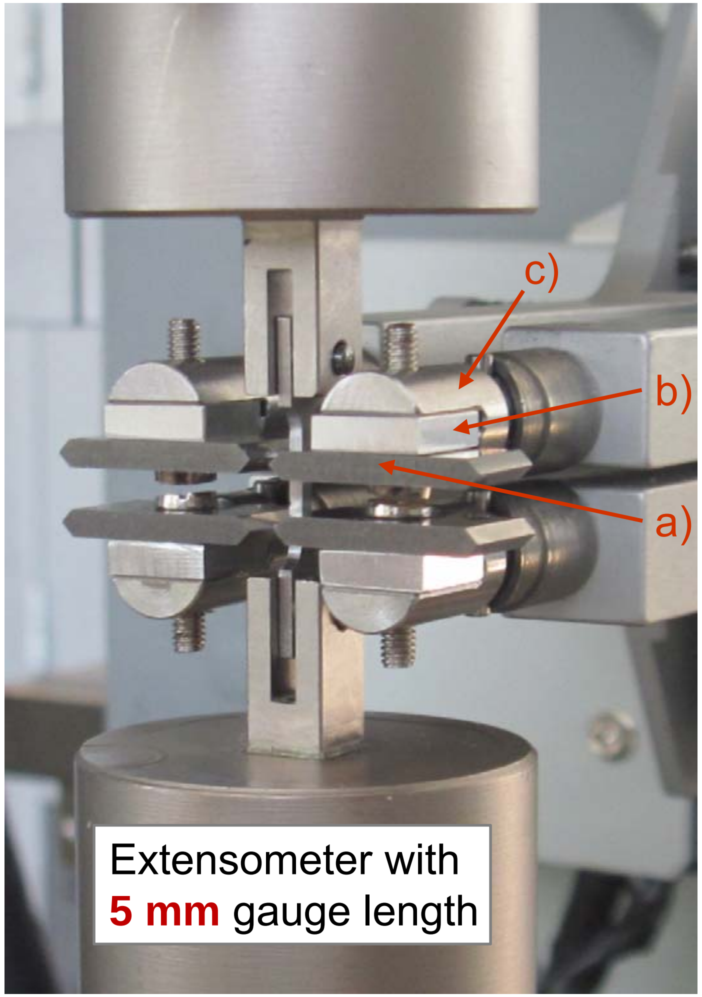
Modification of the extensometer

- Extensometer class 0.5
  - By using standard edges smallest possible gauge length 10 mm
  - Reduction of the gauge length to 5 mm:
    - Spacer, t = 2.5 mm (b)
    - between edge holder (c)
    - and edge (a)
  - Problem: Machine calculates extensions with “set”-gauge length L_e = 10 mm
    - Conversion of extensions to real gauge length necessary:
    - Multiplication of extensions or the measured length change by the factor: $L_{e(set)}/L_{e(real)}$, here: Factor 2



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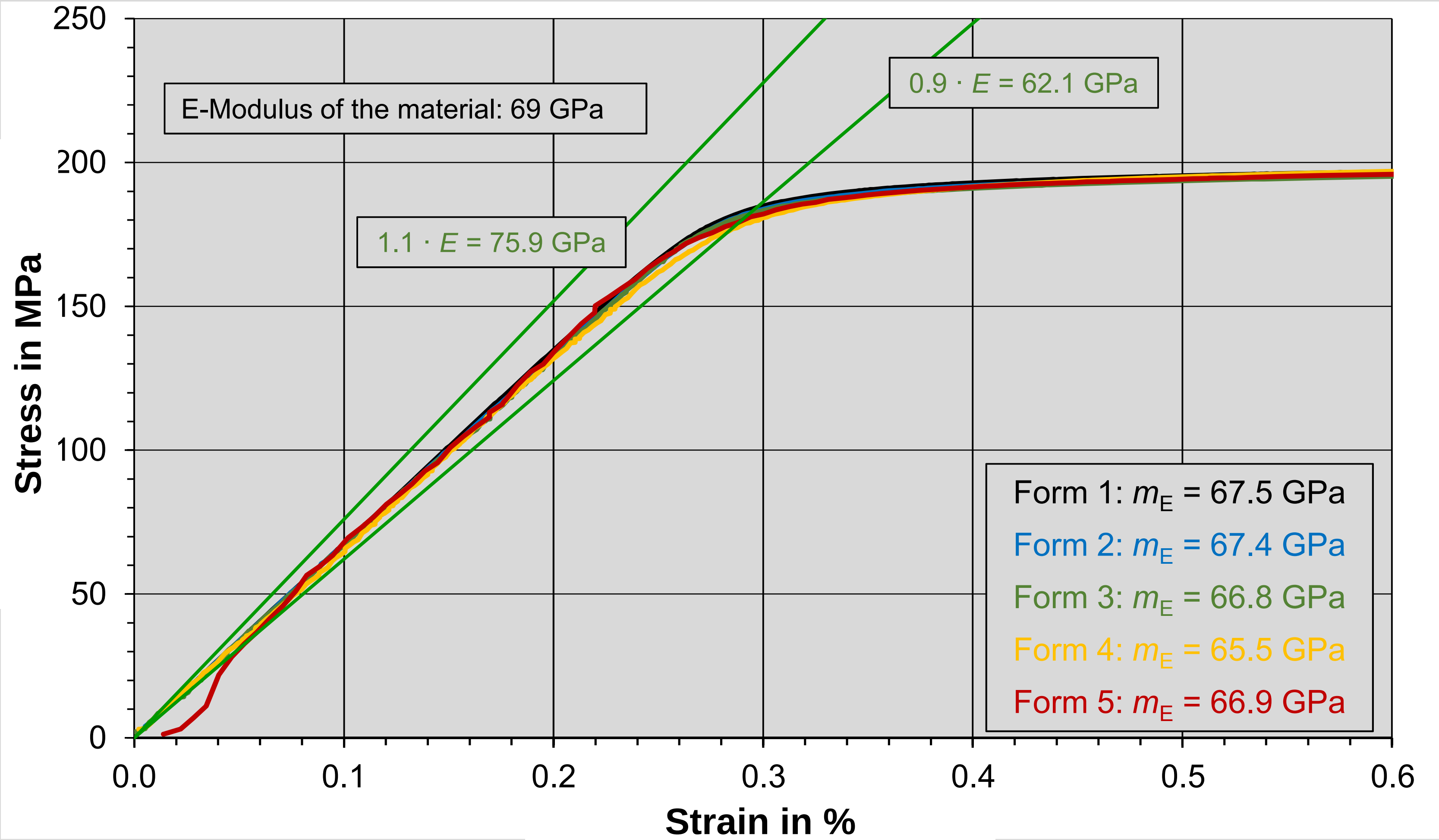
Materials, test piece preparation and testing rates

- AA6016 (AlMg0,4Si1,2), condition T4, 1.0mm thickness
- AA6016 (AlMg0,4Si1,2), condition T6, 1.0mm thickness
- AA5182 (AlMg4,5Mn0,4), condition H111, 1.0 mm thickness
- AA3104 (AlMn1Mg1Cu), condition H19, 0.29 mm thickness

- Test piece preparation by using CNC-milling machine

- Testing rates according to ISO 6892-1:2009, Method A (open loop)

Elastic range for different test piece geometries, material AA 6016-T6



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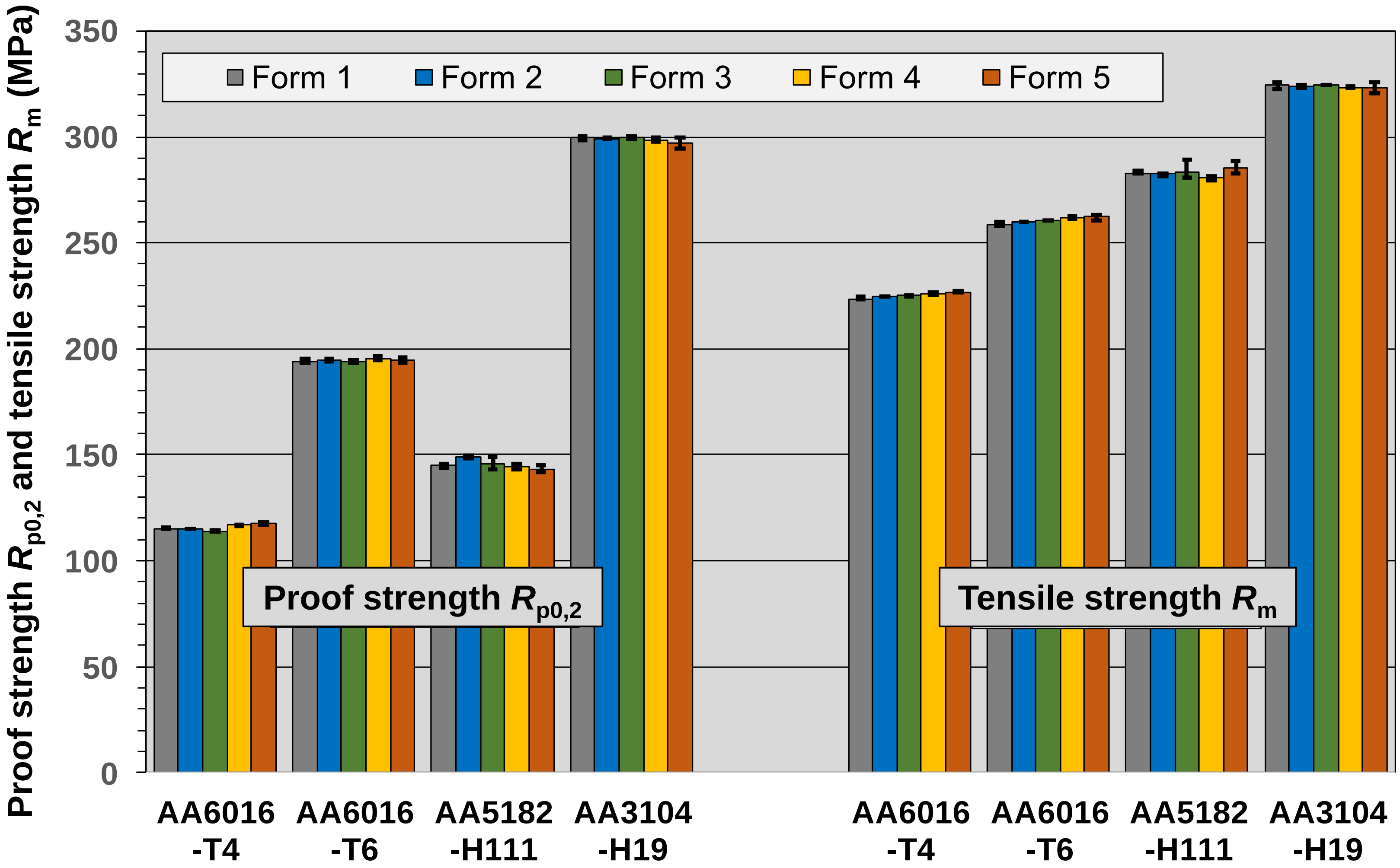
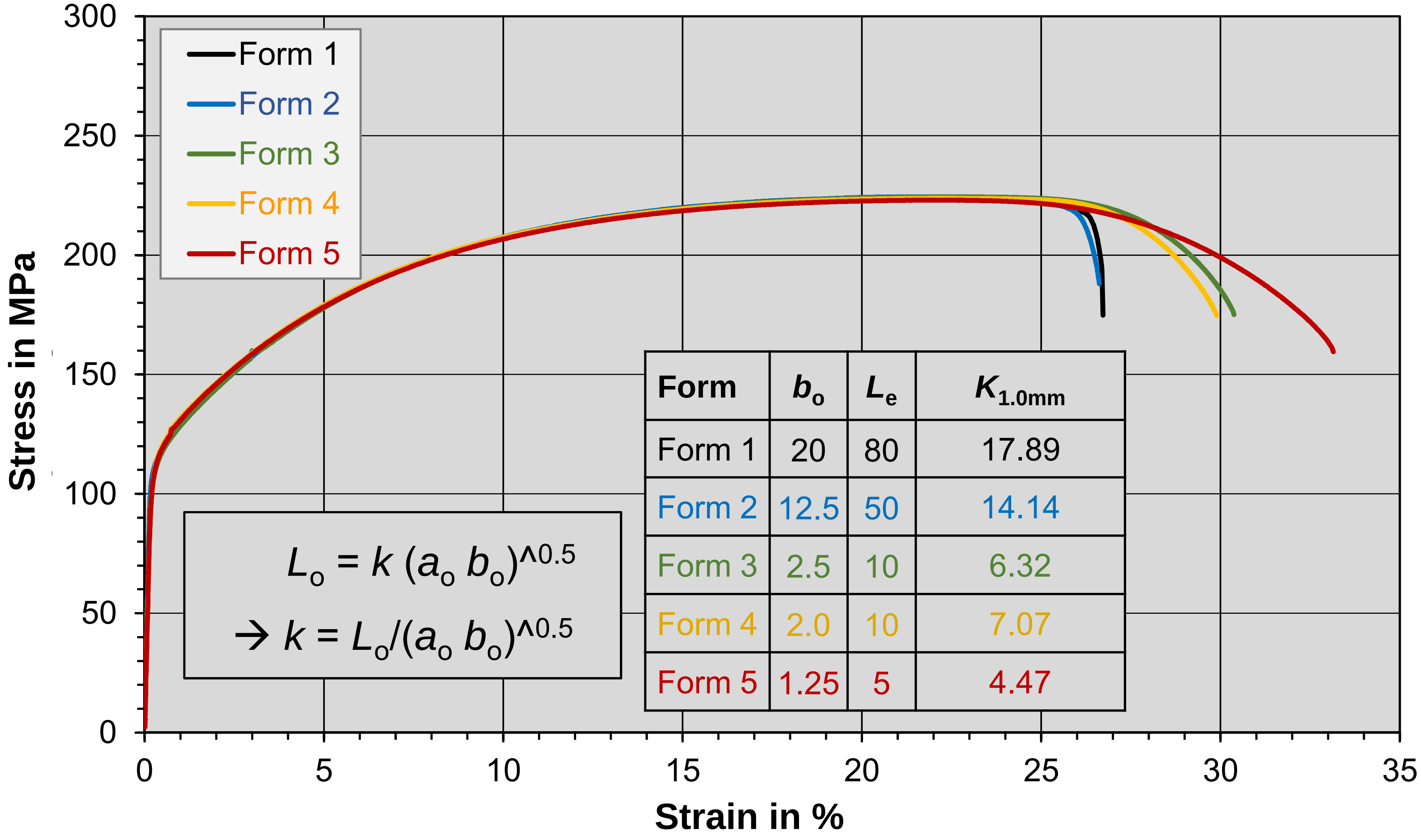
$R_{p0,2}$ and R_m for different test piece geometries



Stress-strain curve for the material AA 6016-T4 1.0 mm thickness



$$L_o = k\,(a_o\, b_o)^{0.5}$$

$$\rightarrow k = L_o / (a_o\, b_o)^{0.5}$$

Form	b_o	L_e	$K_{1.0mm}$
Form 1	20	80	17.89
Form 2	12.5	50	14.14
Form 3	2.5	10	6.32
Form 4	2.0	10	7.07
Form 5	1.25	5	4.47

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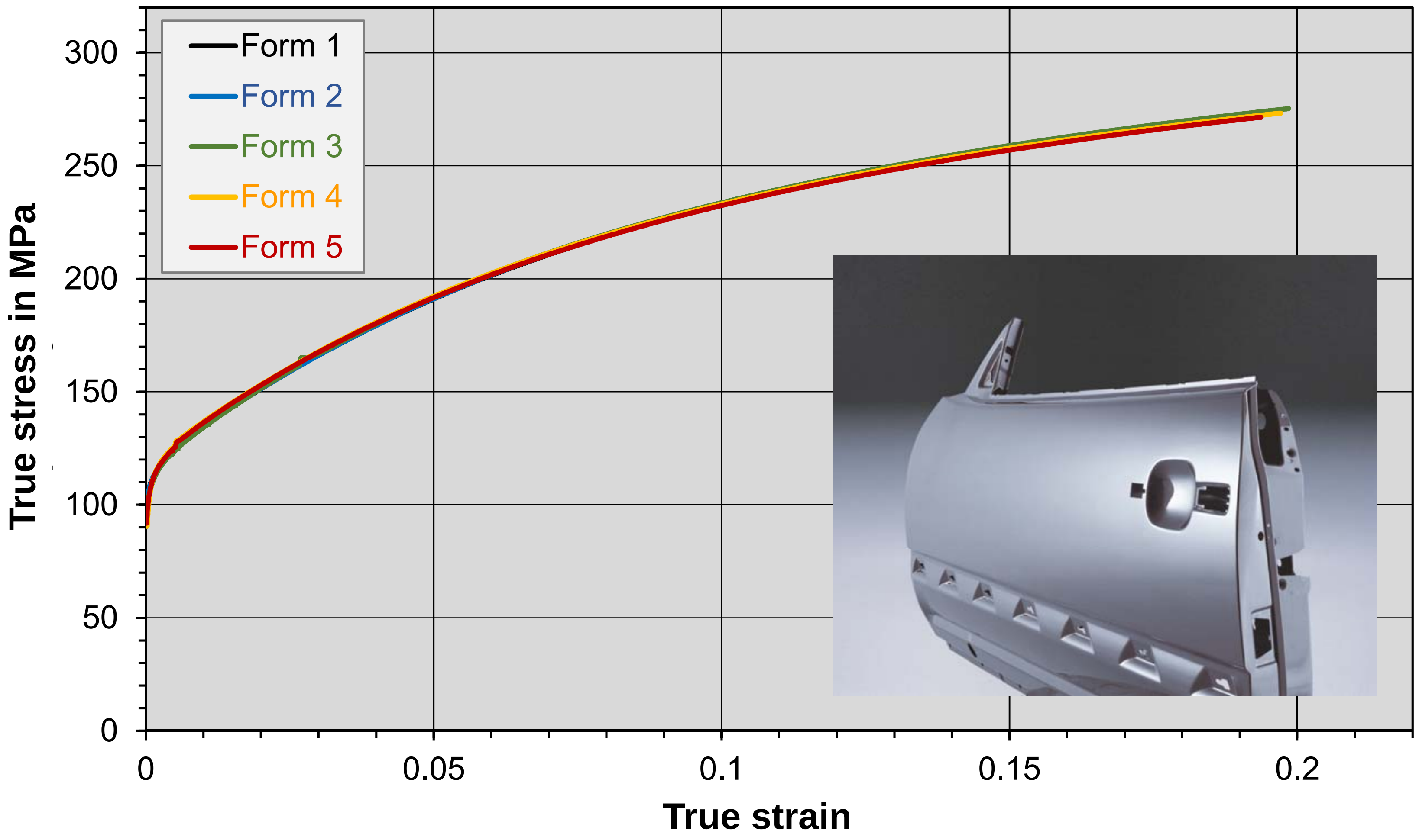
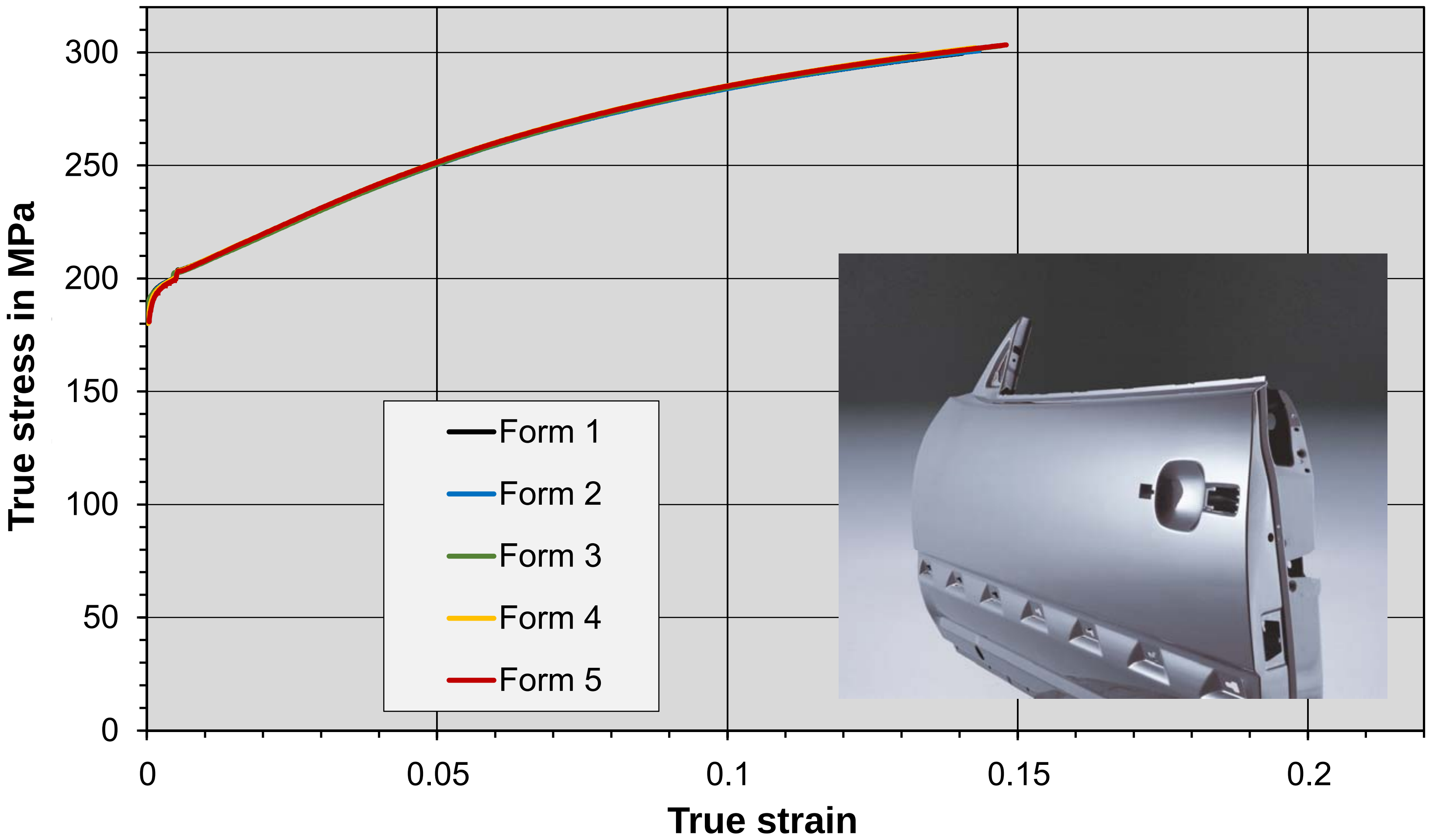
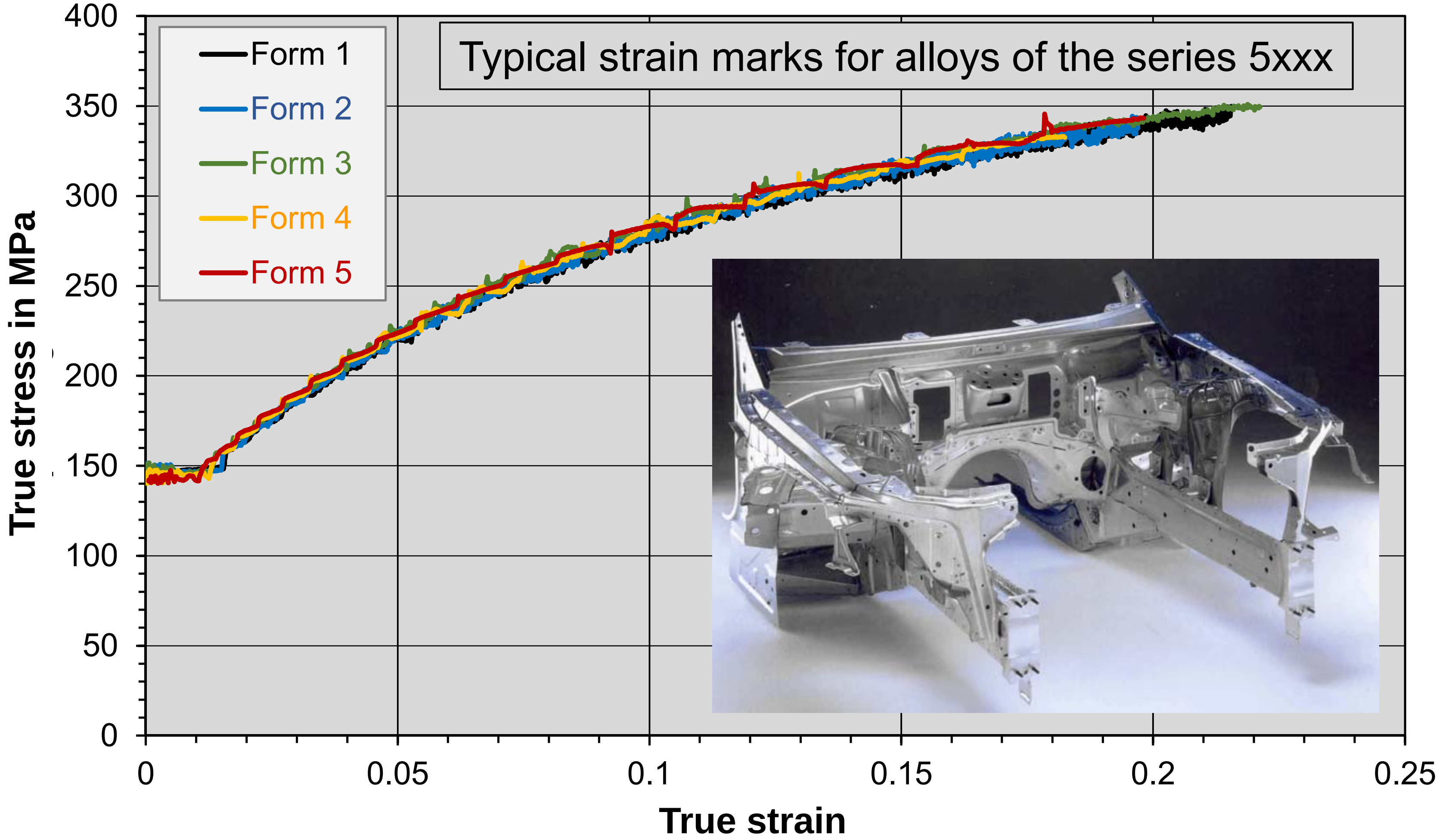
Flow curve for the material AA 6016-T4
1.0 mm thickness



Flow curve for the material AA 6016-T6
1.0 mm thickness



Flow curve for the material AA 5182-H111
1.0 mm thickness



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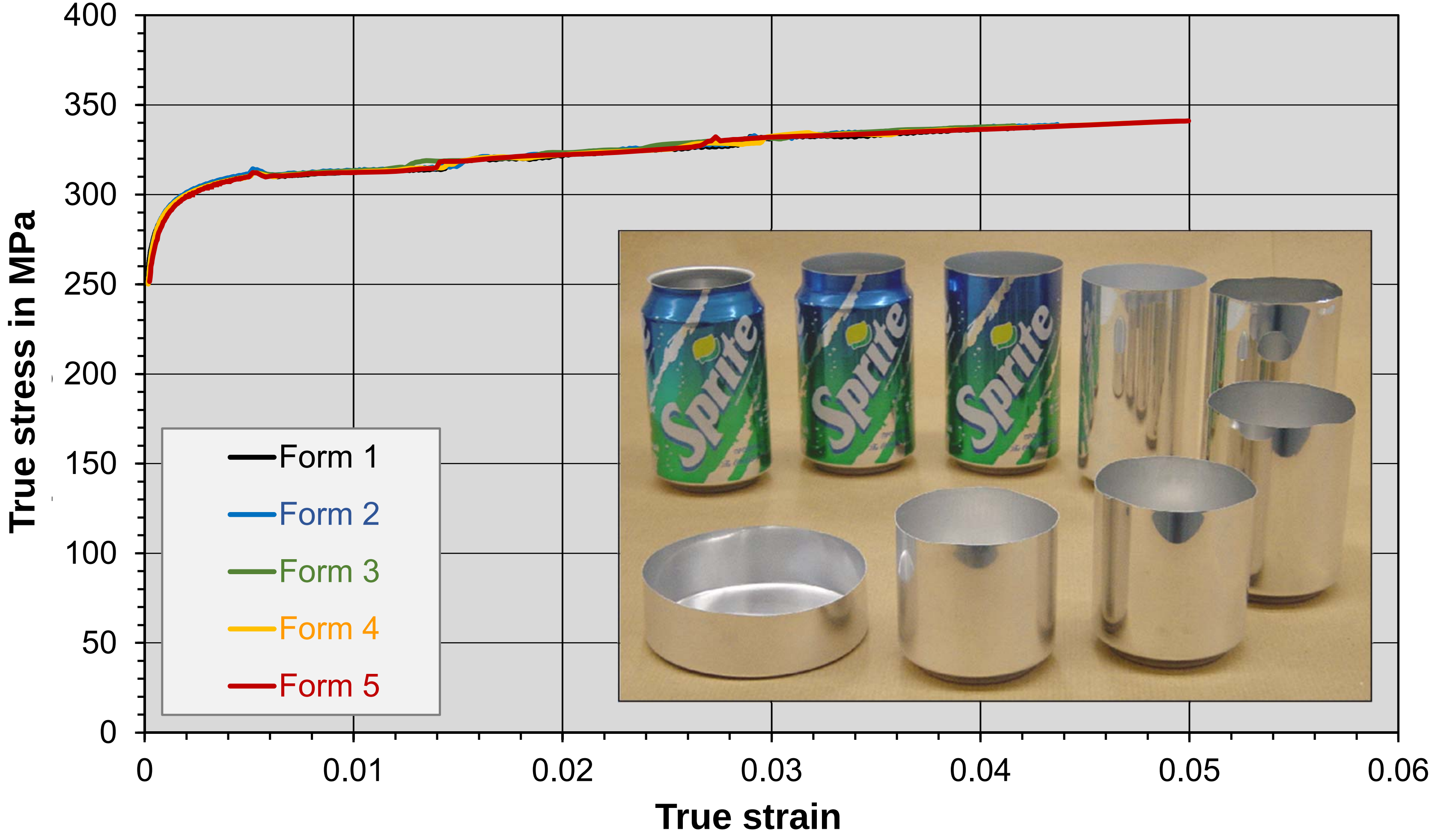
Flow curve for the material AA 3104-H19
0.29 mm thickness



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Is the testing technique used by Hydro useable for steel?

Frame conditions for the usability of the Hydro testing technique for steel

- Available clamping system
  - Limitation of the maximum force → soft and intermediate strength steels
- Available concept for test piece preparation for miniaturised test pieces
  - Was used up to now only for aluminium
- Modulus of Elasticity of steel three times higher than for aluminium
  - For equal stress level in the elastic range only approx. 1/3 of extension as for aluminium

→ Test material DC04, soft, 1 mm thickness

- Material without upper and lower yield strength
- Material is very strain rate sensitive, therefore application of Method A of ISO 6892-1:2009, open loop, (strain rates: for $R_{p0,2}$: 0.00025 s^{-1}, then 0.0067 s^{-1})
- Used test piece geometry: Form 1 and Form 3
- Testing direction: parallel to rolling direction

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Testing results for the test piece geometries 1 and 3 testing direction: Parallel to RD

Form	No.	$R_{p0,2}$ [MPa]	R_m [MPa]	A_g [%]	A_{80mm} [%]	$n_{2\text{-}20}$ [-]	$r_{2\text{-}20}$ [-]
1	1	146.5	306.0	24.3	43.6	0.260	1.908
	2	148.8	305.9	24.6	43.1	0.258	---
	3	146.1	305.5	25.0	43.1	0.260	1.996
	Average	**147.1**	**305.8**	**24.6**	**43.3**	**0.259**	**1.952**
	Std.-Dev.	**1.5**	**0.3**	**0.4**	**0.3**	**0.001**	**0.062**

Form	No.	$R_{p0,2}$ [MPa]	R_m [MPa]	A_g [%]	A_{10mm} [%]	$n_{2\text{-}20}$ [-]	$r_{2\text{-}20}$ [-]
3	1	148.3	313.8	26.7	56.9	0.259	
	2	146.9	313.2	26.8	57.3	0.261	
	3	150.6	314.4	26.3	59.9	0.255	
	4	150.2	312.9	27.2	57.5	0.259	
	5	147.4	314.4	26.7	61.0	0.260	
	Average	**148.7**	**313.7**	**26.7**	**58.5**	**0.259**	
	Std.-Dev.	**1.7**	**0.7**	**0.3**	**1.8**	**0.002**	

NOTE: The different elongations after fracture caused on different coefficients of proportionality, see table on page 6

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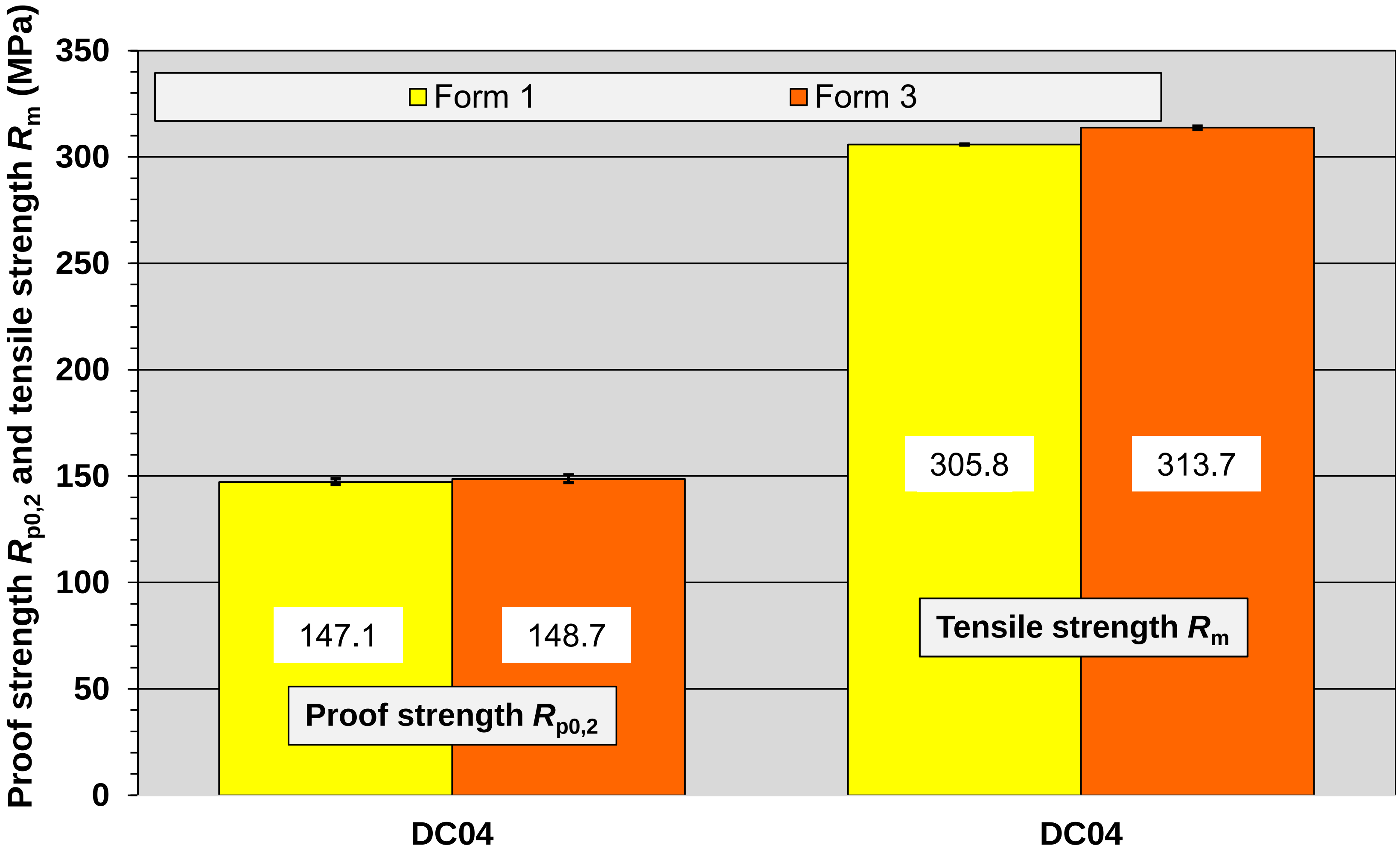
$R_{p0,2}$ and R_m for the test piece geometry 1 and 3
Material DC04



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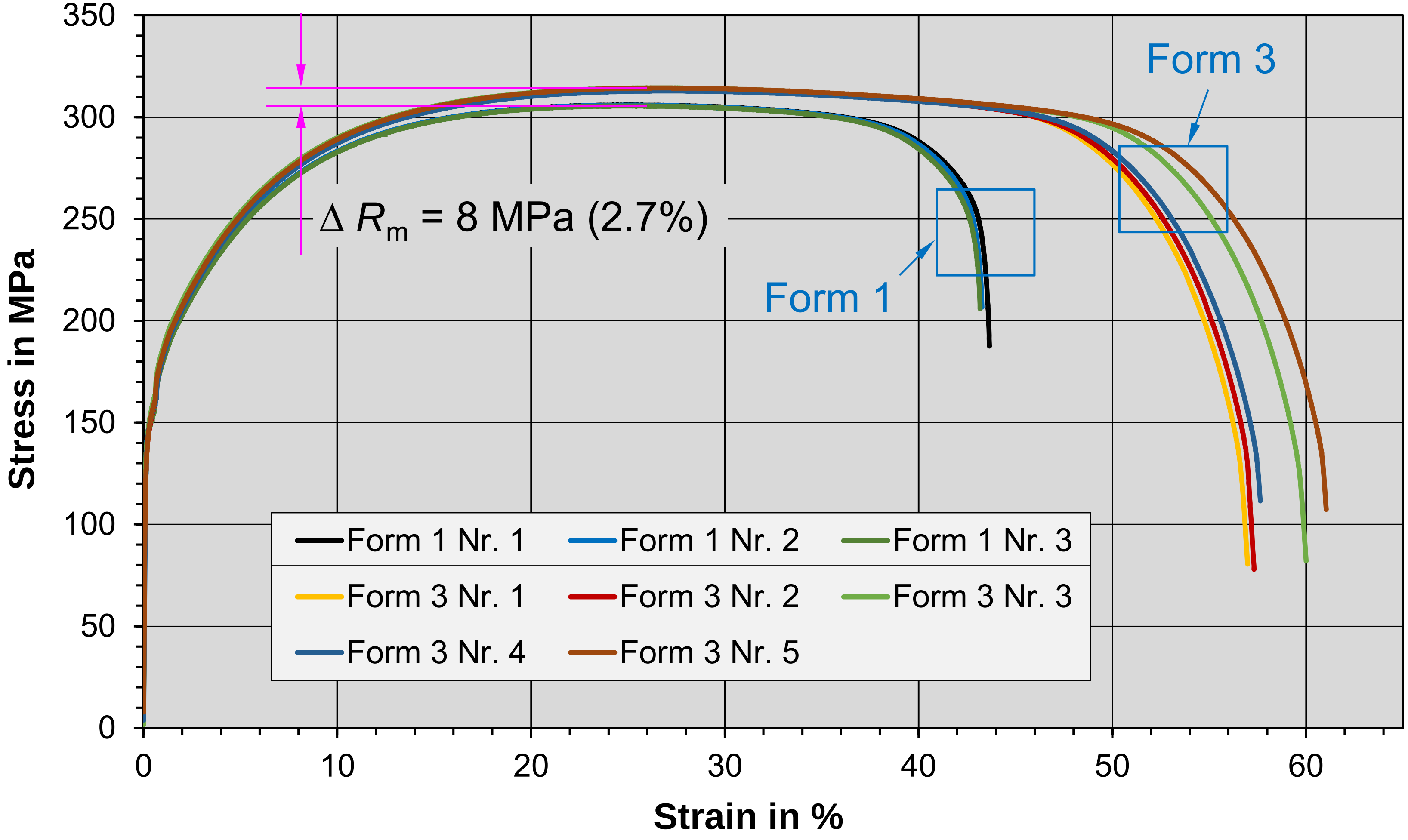
Stress-strain curves for the test piece geometry 1 und 3 Material DC04



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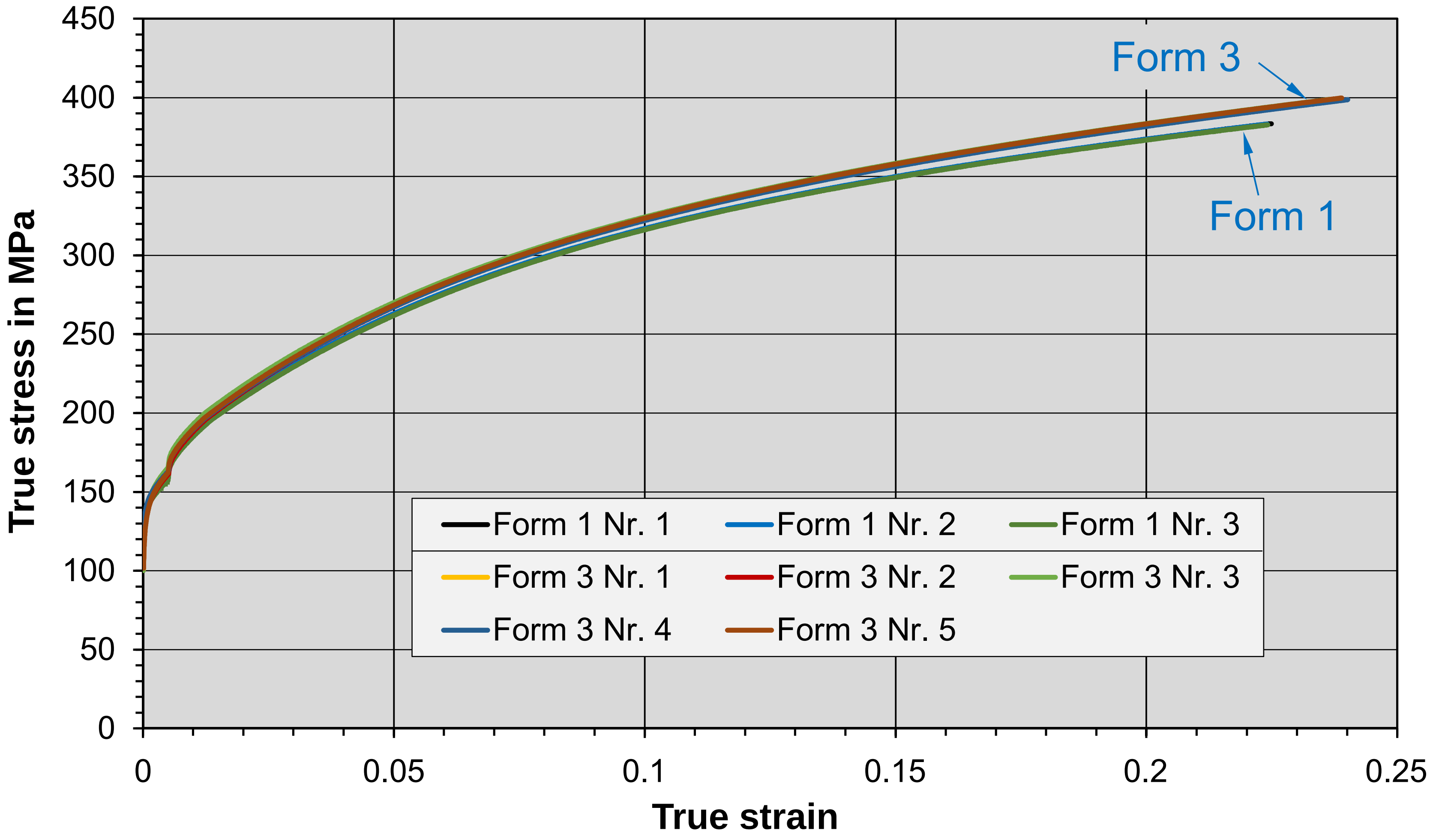
Flow curves for the test piece geometries 1 und 3 Material DC04



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What is the reason for lower tensile strength R_m of test piece geometry 1 for the material DC04?

Consideration

- The same strain rates were used for all materials and test piece geometries
- No differences were observed for the aluminium alloys
- Will a different temperature increase of the test piece during testing will be the cause?
  - Different heat conduction Al/Fe
  - Different ratio of surface/volume of the two test piece geometries

Temperature measurement with thermocouple

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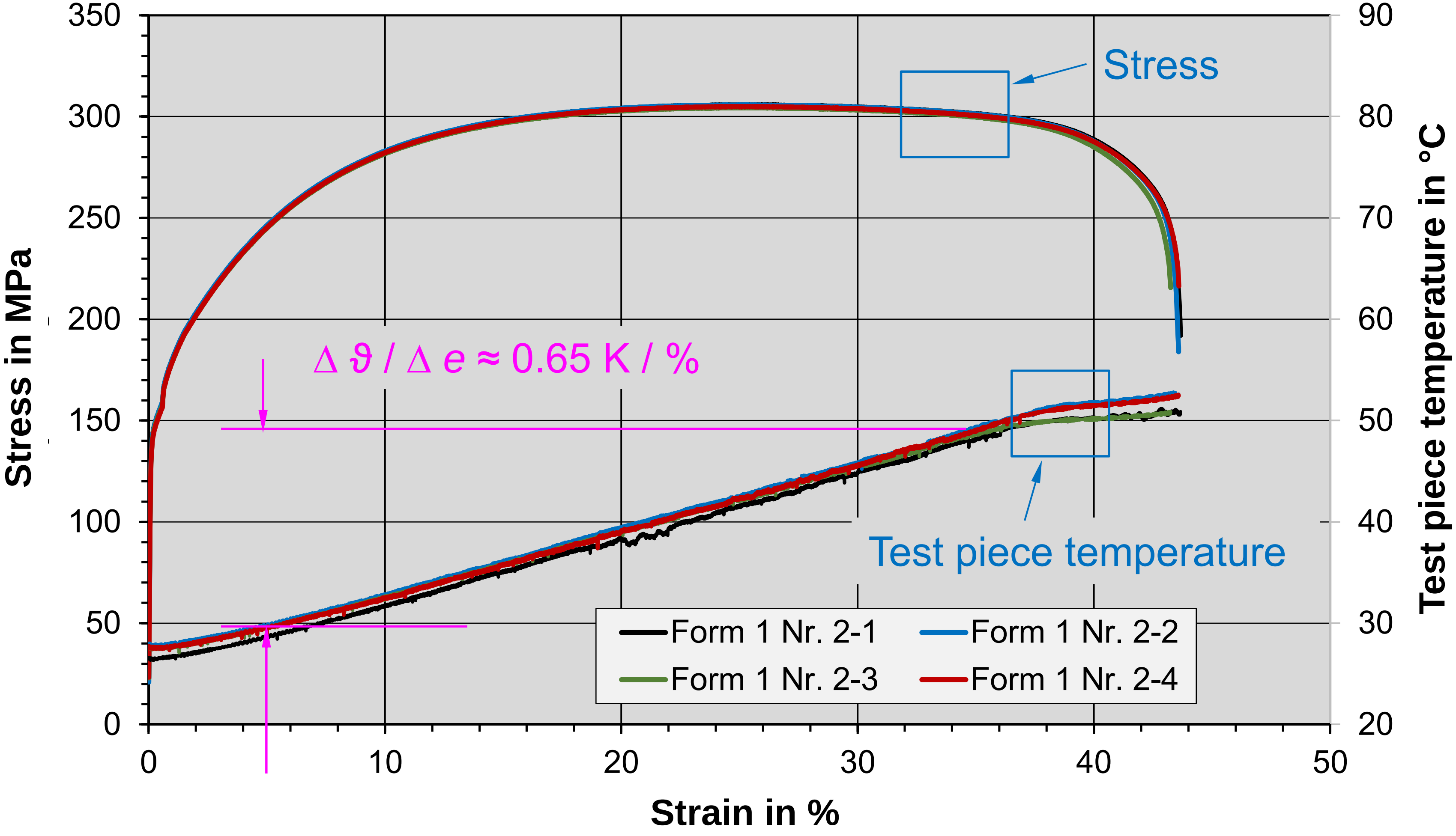
Stress-strain curves and temperature-strain curves for test piece geometry 1, material: DC04



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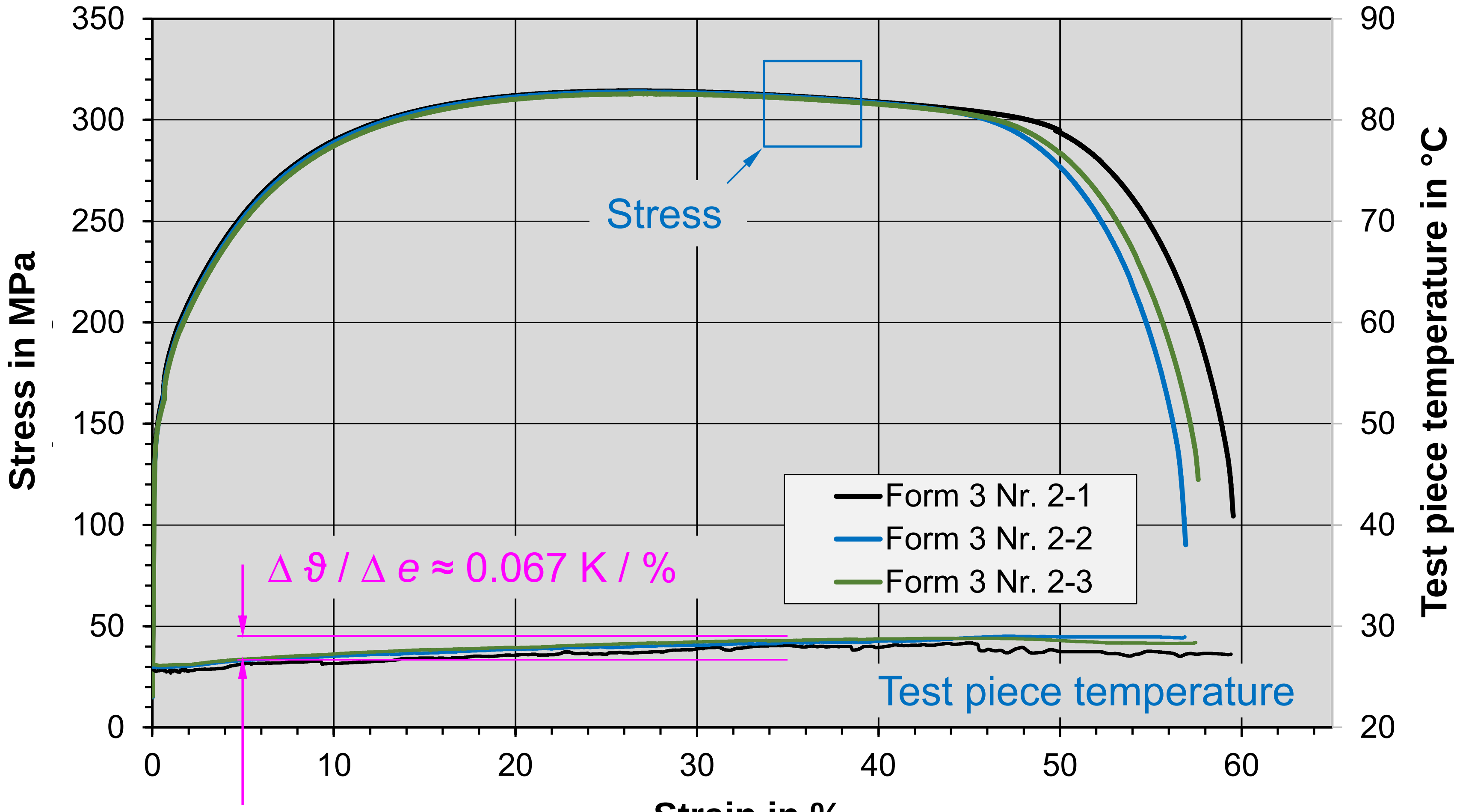
Stress-strain curves and temperature-strain curves for test piece geometry 3, material: DC04



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Summary (1/2)

The testing technique developed by Hydro for the determination of local strength properties and flow curves from deformed component areas by using miniaturised test pieces fulfils the defined requirements and provide results, which are nearly identical with those of standard test pieces geometries.

This was verify for:

- Various aluminium alloy types (3xxx, 5xxx with strain marks and 6xxx)
- Various conditions (soft, artificial aged, as rolled)
- Two very different thicknesses (0.29 mm and 1.0 mm)

- Applicable in the normal industrial environment, this means by using mainly standard testing equipment.

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Summary (2/2)

The presented testing technique is also applicable for soft and intermediate strength steels.

This was verified for the steel DC04.

- A slightly higher tensile strength R_m was determined for the steel DC04 by using miniaturised test pieces. This may be caused by the clearly smaller temperature increase during testing for these test pieces.

- For high strength steels the clamping device has to be produced out of materials with higher strength.

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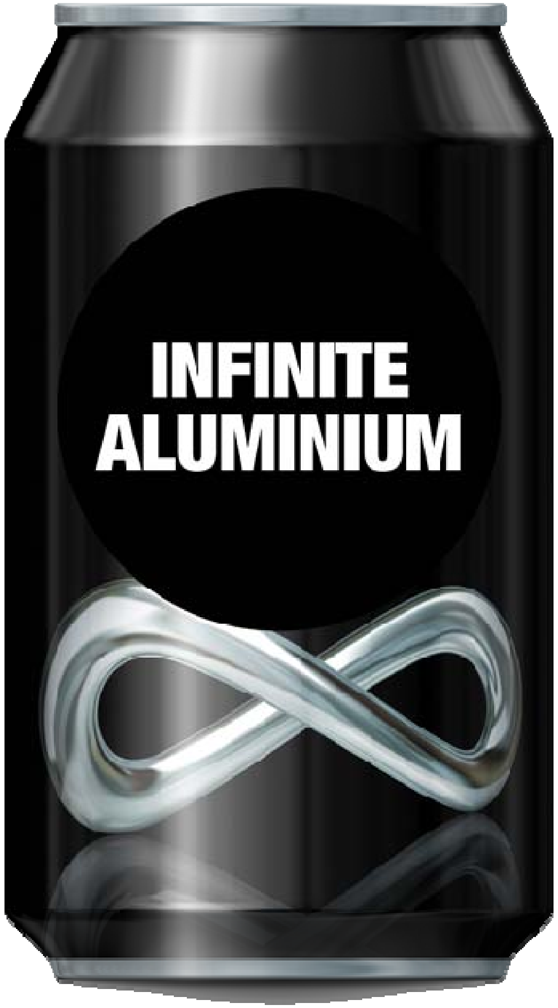

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