Evaluation and Parametrization of Self-piercing Riveting by Using Metamodels

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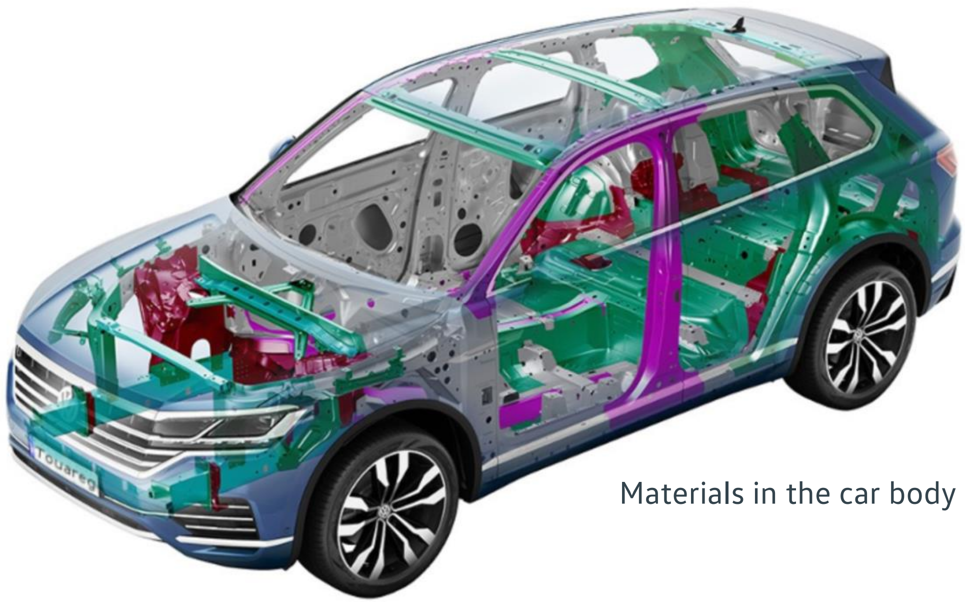
Introduction

The new VW Touareg: multi-material design

Ca. 2.500 Rivets in the car body structure



materials:

- cold formed steel
- hot formed steel
- aluminium sheet
- aluminium profile
- aluminium cast

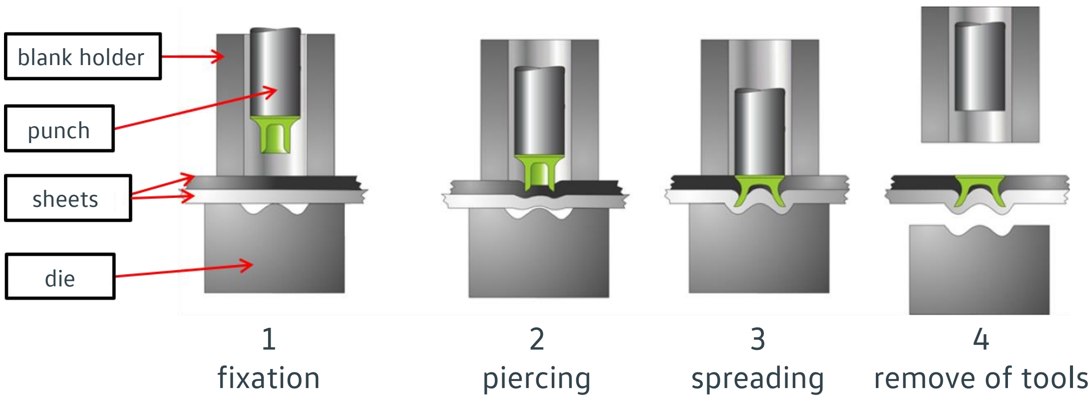
Materials in the car body structure of the new VW Touareg

combinations of different aluminium alloys and aluminium to steel require mechanical joining technique

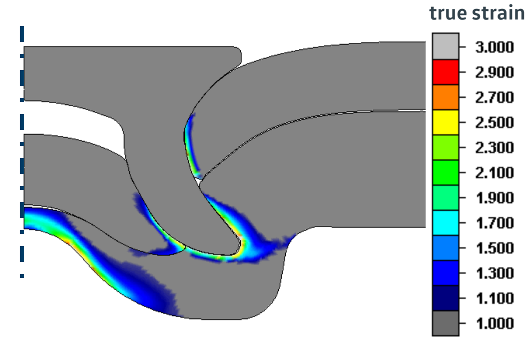
→ Self piercing riveting (SPR) is a suitable, high potential and qualified technology for multi-material car bodies

Introduction

Self piercing riveting – process and quality parameters



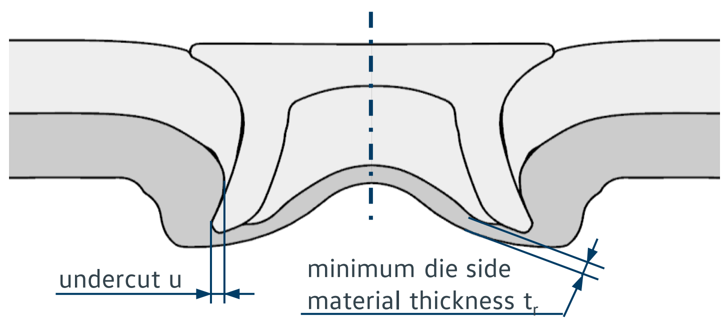
process steps of self piercing riveting



process animation

mechanical joining process with:

- high local deformation of the sheets including piercing of upper sheet
- Low deformation of the rivet to ensure spreading and generation of undercut



Cross section and quality parameters

Stand: 06.06.2018; Verfasser: Dr. M. Israel, Tel: +49 5361 963726; WOST Metamodel SPR Israel_2018-05-30.pptx

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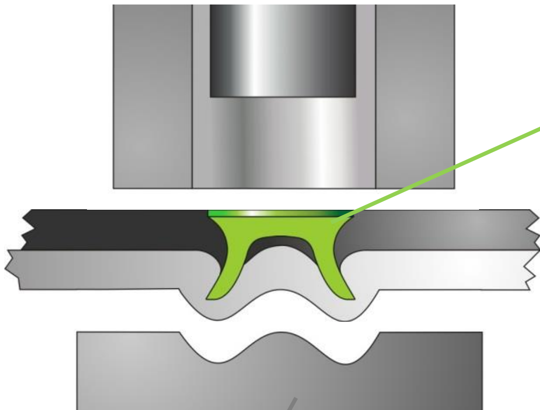
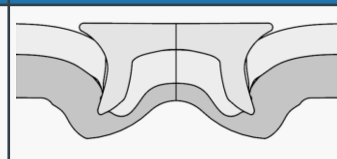
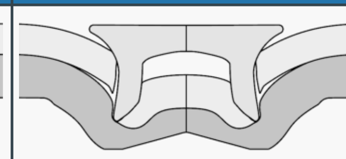
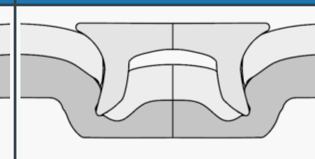
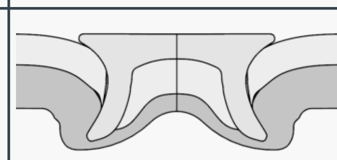
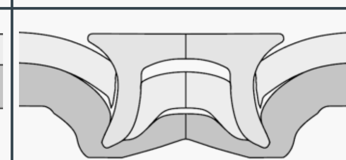
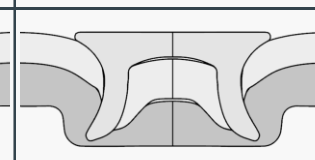
Process layout SPR

Relevant influencing parameters – rivet and die



rivet: different types and lengths

die: different shapes

rivet length	die shape A	die shape B	die shape C
4.0 mm			
5.0 mm			

example: 3 die shapes and 2 rivet lengths (results from FEM simulation)

amount of combinations to be tested for finding the best parametrization

Process layout SPR

Two cases in process parametrization

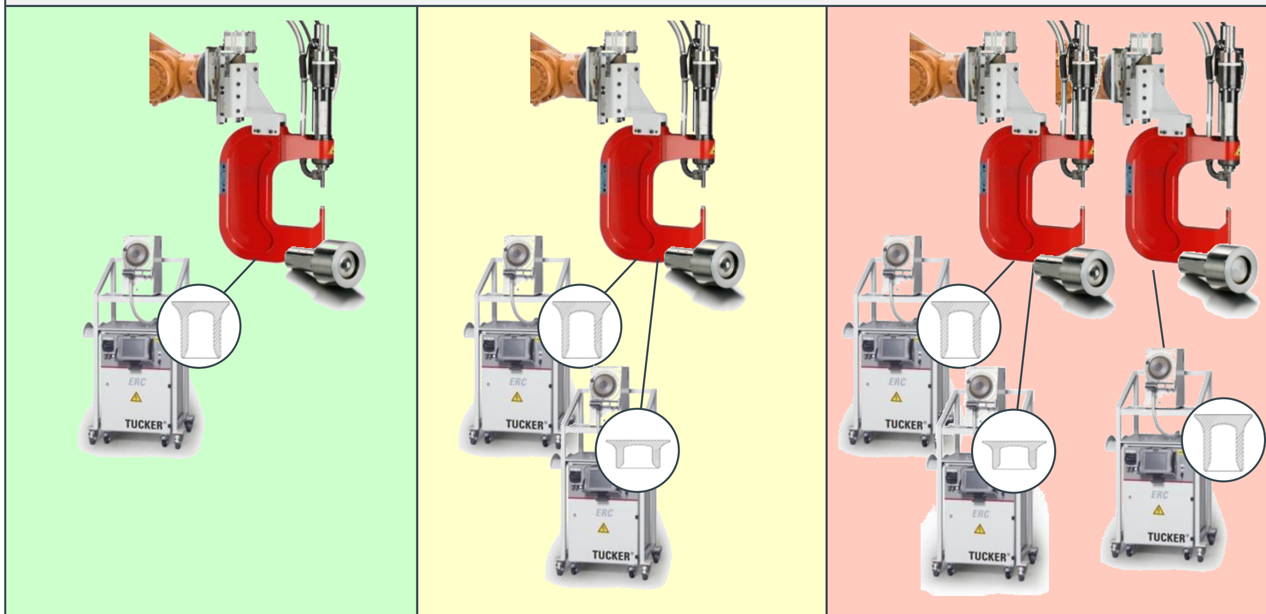
A

one single material-thickness-combination (MTC)

result of single MTC layout is always one die (one tong) and one rivet

B

different material-thickness-combinations (MTC)



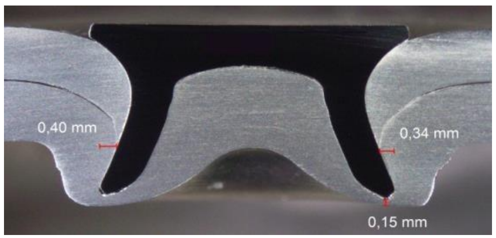
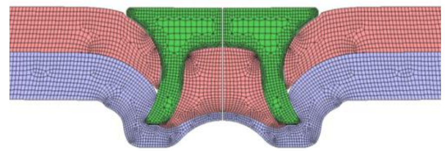
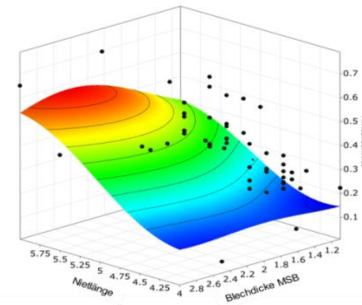
Picture source: Tucker GmbH

parametrization

good ← bad

Process layout SPR

Possibilities

	experimental	simulative	metamodel-based
picture			
effort	High (joining, cutting, grinding, microscope)	Medium (model qualification, simulation of each combination)	Low (with existing metamodel in real-time)
status	state of the art, most used	state of the art, rarely used	new

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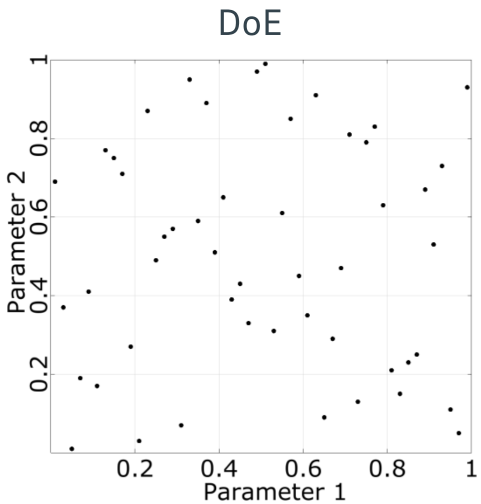
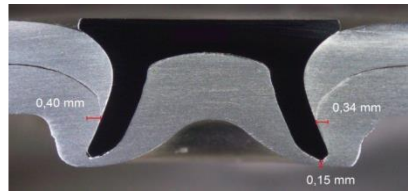
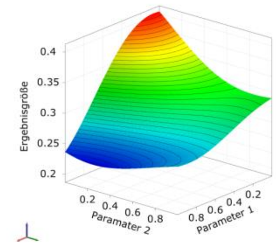
Metamodelling SPR

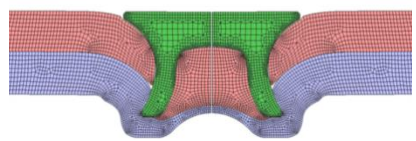
Using experimental or simulative data?

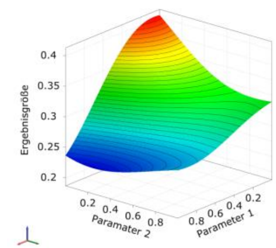




experiment




simulation



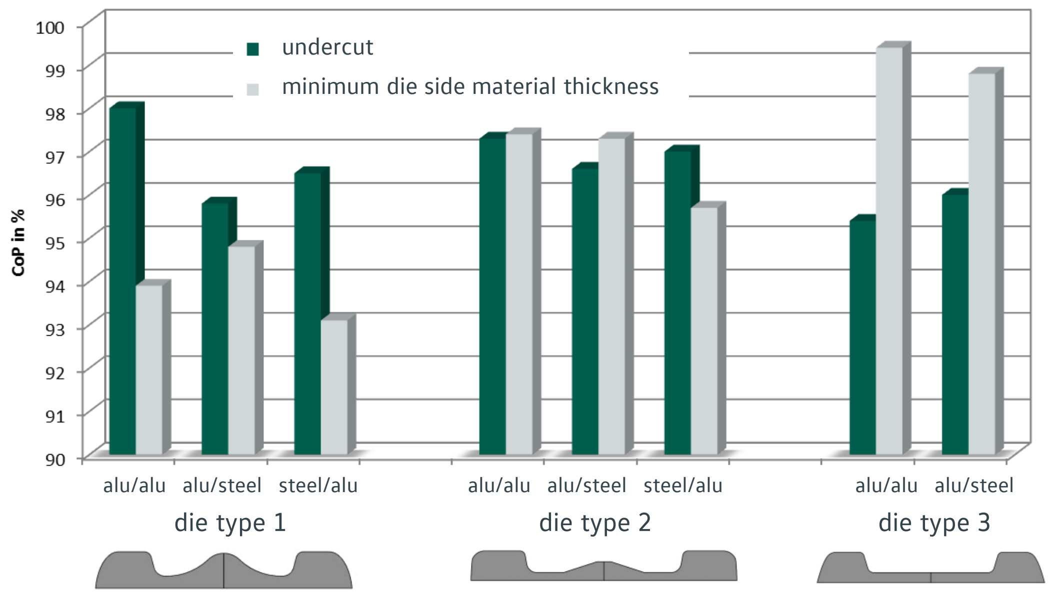
<u>two main disadvantage of experimental data:</u>

- not all parameter realisations are possible → bad DoE
- high effort of analysis for the neccessary amount of data

⇨ **metamodels based on simulation data including verification with experiments**

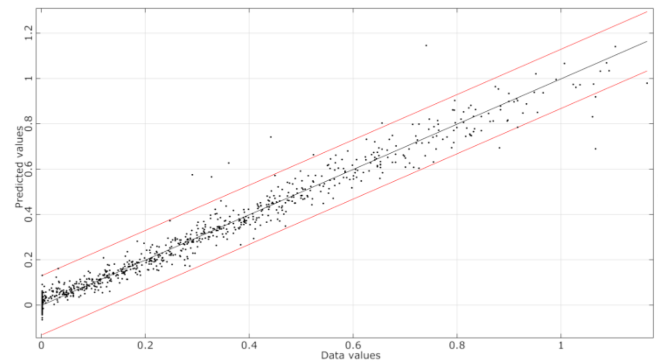
Metamodelling SPR

Quality of choosen metamodels (CoP)



average CoP of all dies and combinations:

- undercut: 96,5%
- minimum remaining sheet thickness: 96,3%



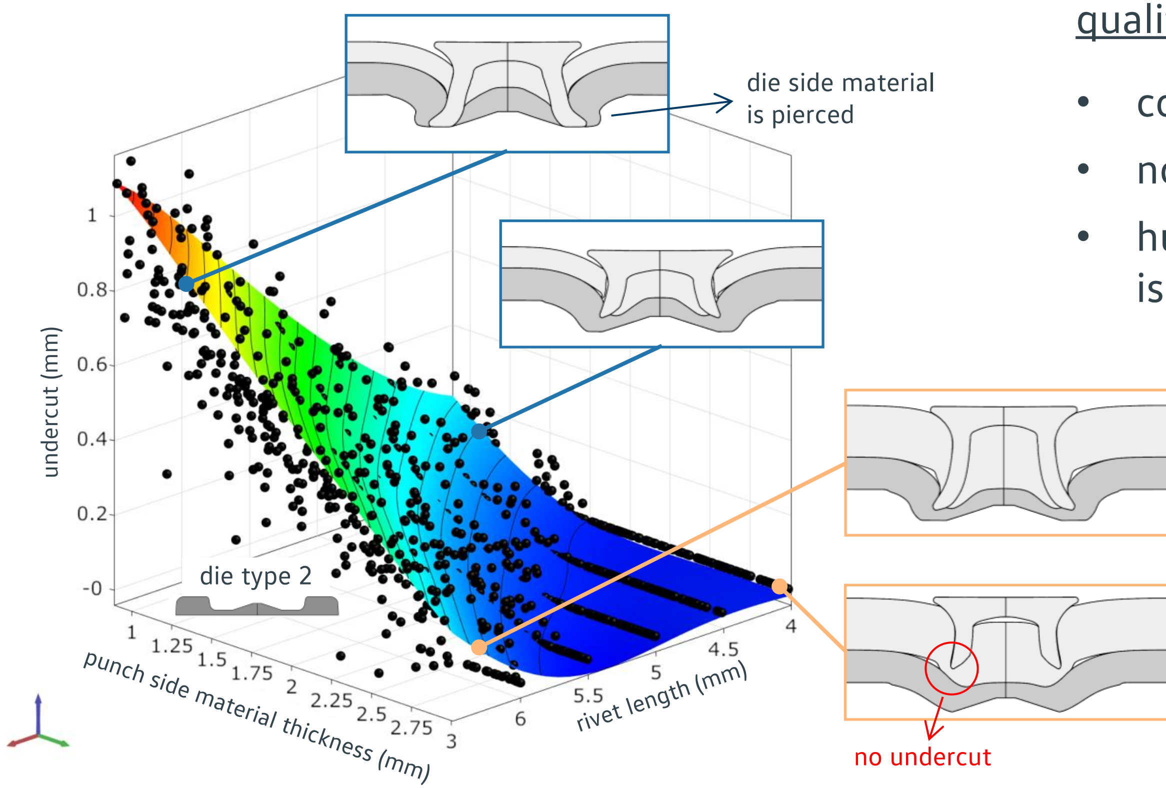
Statistical data			
Max Error:	0.406671	Mean Error:	0.027162
Root Mean Square Error:	0.0435702	CoP:	0.973466

scatter plot of undercut for die type 2 (alu/alu)

- using anisotropic kriging approximation
- very high prognosis quality
  → necessary for parametrization on metamodel

Metamodelling SPR

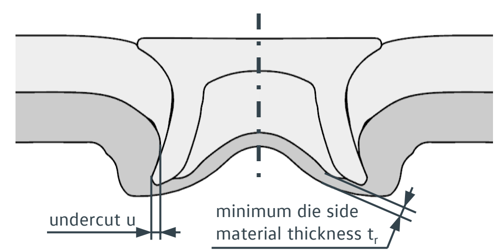
Quality of choosen metamodels (check of already known relations)



metamodel of undercut for die type 2 (Alu/Alu)

<u>quality of metamodel for undercut:</u>

- correct tendencies
- no inexplicable waviness
- huge area of zero-value is good approximated



Metamodelling SPR

Parameter relevance (example: die type 2, steel/aluminium)

	t2_Blechdicke	t1_Blechdicke	Nietlaenge	t1_Rp02	t1_Nachverfestigung	t2_Nachverfestigung	t2_Rp02	Nietkopfendlage_mm	Reibwert_Niet_SSB_mu	Reibwert_Niet_SSB_m	Reibwert_Niet_MSB_mu	Reibwert_Niet_MSB_m	Reibwert_MSB_MATRIZE_mu	Reibwert_MSB_MATRIZE_m	Reibwert_SSB_MSB_mu	Reibwert_SSB_MSB_m	t2_Verfestigungsexponent	t1_Verfestigung_Exp	Total
minimum die side material thickness	57.1 %	22.2 %	18.9 %	5.5 %	2.9 %	1.6 %	0.8 %	5.1 %	0.0 %	0.3 %	0.0 %	0.0 %	6.3 %	7.9 %	0.0 %	0.6 %	0.0 %	0.3 %	95.7 %
process force	5.7 %	21.7 %	27.0 %	6.5 %	2.6 %	1.7 %	1.1 %	31.3 %	1.7 %	1.7 %	0.0 %	0.1 %	2.6 %	3.0 %	0.4 %	0.4 %	0.0 %	0.5 %	87.6 %
undercut	13.2 %	23.6 %	63.1 %	1.1 %	1.6 %	0.6 %	0.0 %	9.5 %	1.4 %	2.1 %	0.3 %	0.2 %	0.1 %	0.6 %	0.0 %	0.0 %	0.3 %	0.2 %	97.0 %

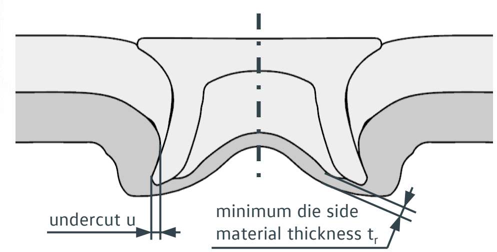
material thickness

rivet length

Position of rivet

material parameters

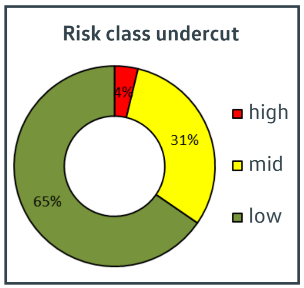
friction parameters

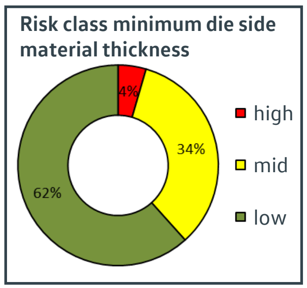


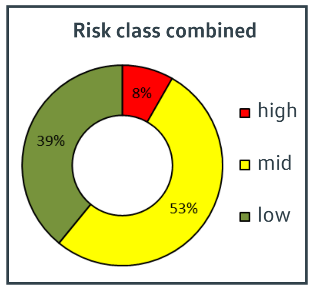
Metamodelling SPR

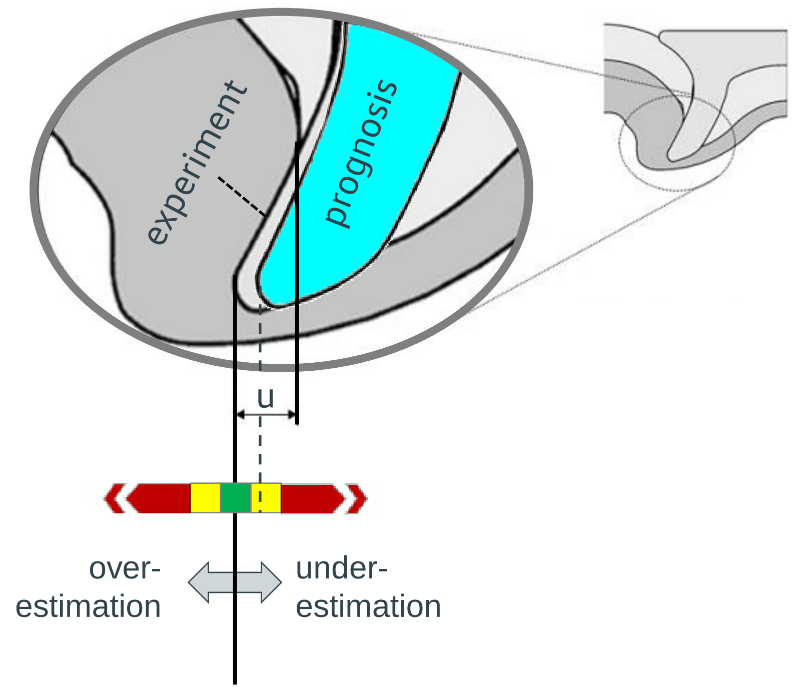
Quality of choosen metamodels (validation with experiments)

Risk classes						
Value in experiment	**high +**	**mid+**	**low +**	**low -**	**mid -**	**high -**
0-0,25 mm	> 0,1	0,05 to 0,10	0,00 to 0,05	0,00 bis - 0,05	-0,05 bis -0,10	< -0,10
> 0,25 mm	> 40 %	20% to 40%	0% to 20 %	0 to -20%	-20% to-40%	< -40%
	Area of overestimation			Area of underestimation		









- very good prognosis quality based on verification of 133 material and thickness combinations
- nearly idendical prognosis quality like FEM simulation

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Metamodel-based process layout

Step 1: Metamodel response integrated in Excel

Input desk (material and thickness combination, rivet)				
material rivet side	thickness Rivet side (mm)	material die side	thickness die side (mm)	rivet length (mm)
AA6016-1	1,5	HX340LAD	2	4,50
AA6016-1	1,5	HX340LAD	2	5,00
AA6016-1	1,5	HX340LAD	2	5,50
AA6016-1	1,5	AA6016-1	1,5	4,50
AA6016-1	1,5	AA6016-1	1,5	5,00
AA6016-1	1,5	AA6016-1	1,5	5,50

Results for different dies		
A	B	C

Detailed Informations (example for die A)		
undercut (mm)	min. thickness (mm)	joining force (kN)
0,34	0,42	47,19
0,47	0,45	50,69
0,63	0,42	54,78
0,15	0,35	42,49
0,28	0,23	47,34
0,45	0,09	52,09

- excel-integrated value response from different metamodels allows real-time evaluation of joinability for different material and thickness combinations of sheets (MTC), rivets and dies
- finding optimal dies and rivets for a cluster of MTC is difficult

Metamodel-based process layout

Step 2: Optimated layout for a cluster of MTCs

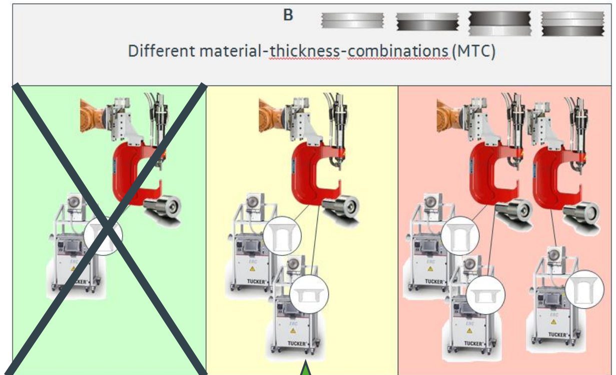
Input desc				
	material rivet side	thickness rivet side (mm)	material die side	thickness die side (mm)
MTC 1	AA6016-3	1,1	AA6016-1	1,3
MTC 2	AA6016-1	1,5	AA6016-1	1,5
MTC 3	AA6016-3	2,0	AA6016-1	1,5
MTC 4	AA6016-3	2,0	AA6016-1	1,3

Chose dies (fill with „X“)			
A	B	C	xxx
x	x	x	

Chose rivet length in mm (fill with „X“)					
4	4,5	5	5,5	6	6,5
x	x	x	x	x	x

Results							
Combination of die and rivet	**Quality value**			**MTC 1**	**MTC 2**	**MTC 3**	**MTC 4**
	worst MTC	**2. worst MTC**					
1	126	146	**die**	A	A	A	A
			rivet	4,5	4,5	5,5	5,5
2	126	146	**die**	A	A	A	A
			rivet	4,5	4,5	6	6
3	102	128	**die**	B	B	B	B
			rivet	4,5	4,5	6	6
4	102	118	**die**	B	B	B	B
			rivet	4,5	4,5	6,5	6,5

optimal process layout



unique tools not possible for this cluster example

Automated testing and optimization of suitable tools including minimization the number of dies and rivets

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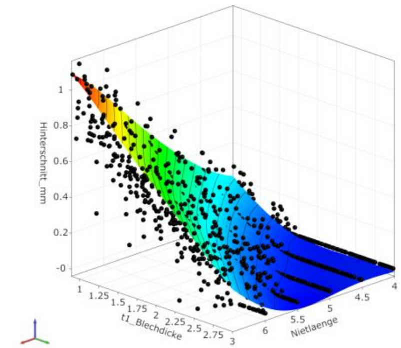
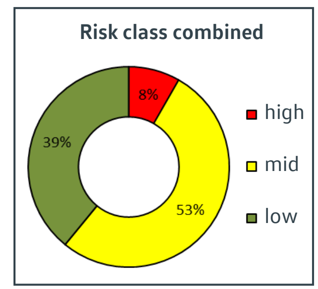
Evaluation and Parametrization of Self-piercing Riveting by Using Metamodels

Summary

- very powerful metamodels possible,
  based on a large database using high quality FEM model
- metamodels approximated with anisotropic kriging
  show best prognosis
- validation on experiments helps to improve
  prognosis quality (identical prognosis quality like
  direct FEM simulation)
- process layout for single MTC and for clusters
  of much MTCs is feasible in a very short time





Metamodel based process layout will be a powerful tool to shorten development time and to reduce facility costs.

Thank you for your attention