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파워풀 대구

FIX All on AI

Future Innovation tech eXpo Conference 2025

스탬핑공정에서 성형품질 안정화를 위한 스마트 금형제어 방안

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김태효 수석연구원

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1. Material scatter
2. Smart stamping process
3. Technology
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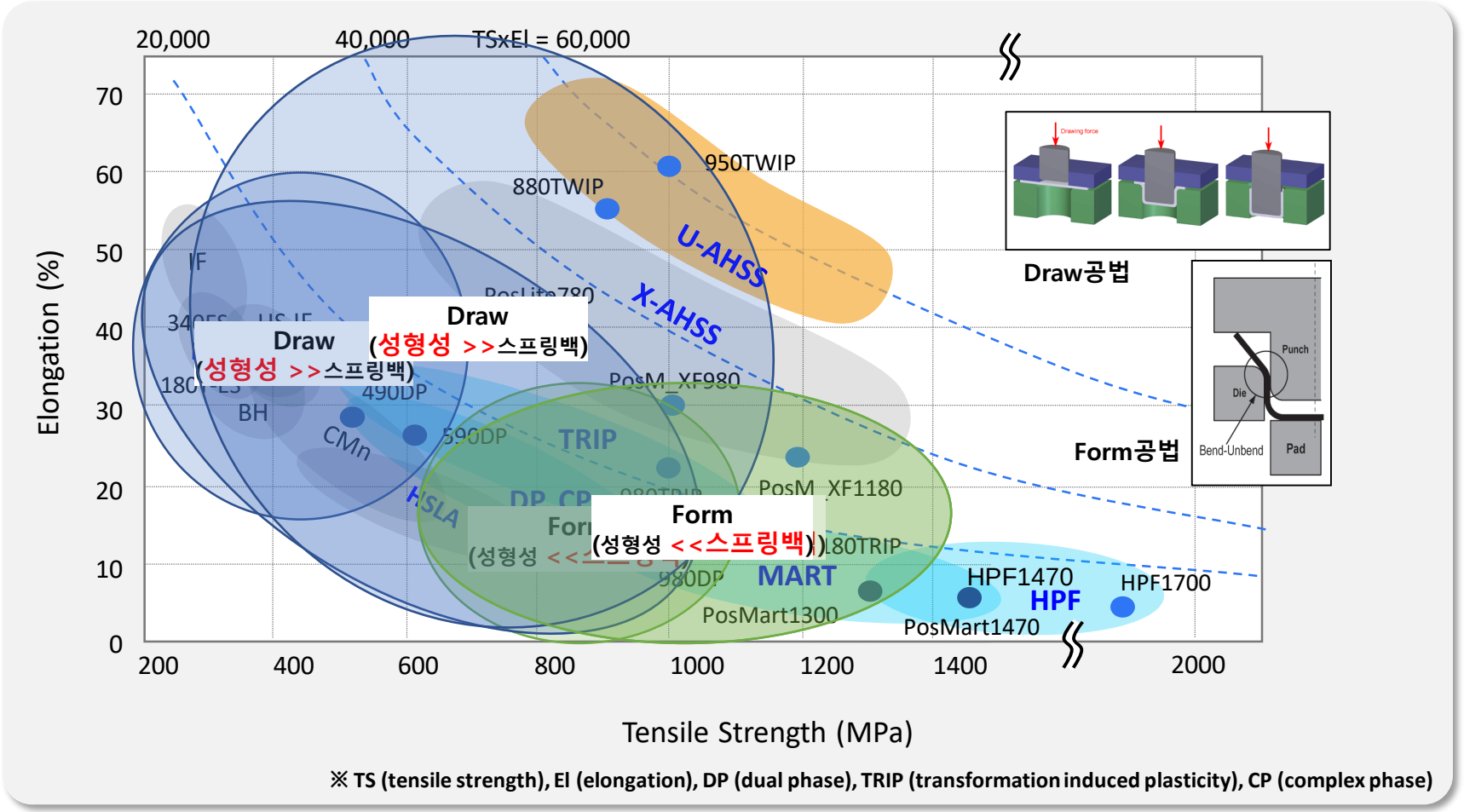
5. Summary

Material Scatter

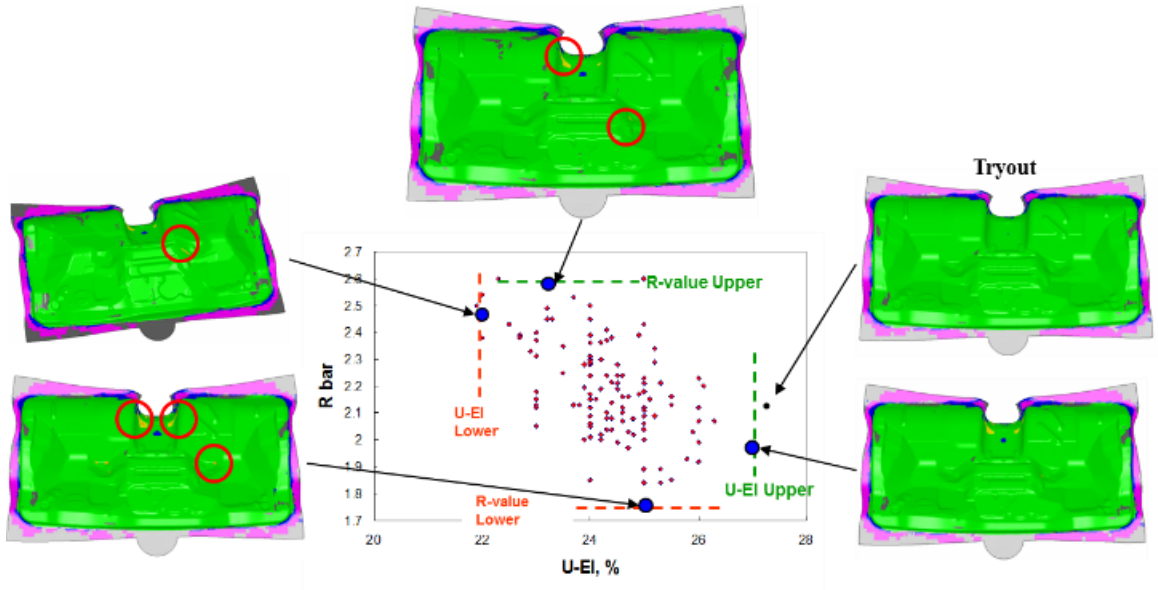
- **Steel development**
  - **Safety regulation, CO2 reduction, competition with AL, etc.**



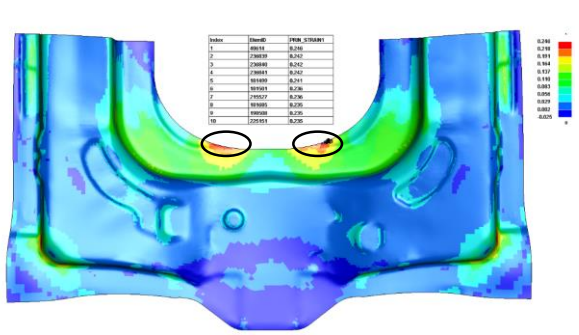
※ TS (tensile strength), El (elongation), DP (dual phase), TRIP (transformation induced plasticity), CP (complex phase)

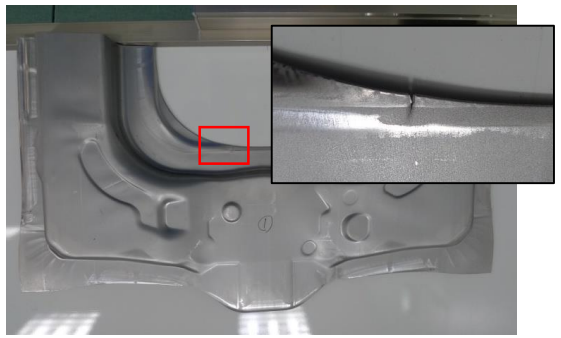
Material Scatter

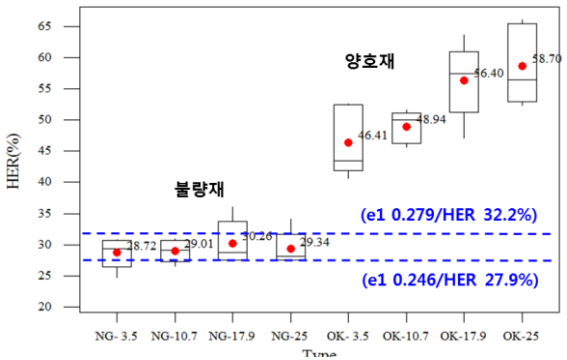
- Material scatter vs. Formability
  - Design complexity & Product quality
  - Global vs. local formability

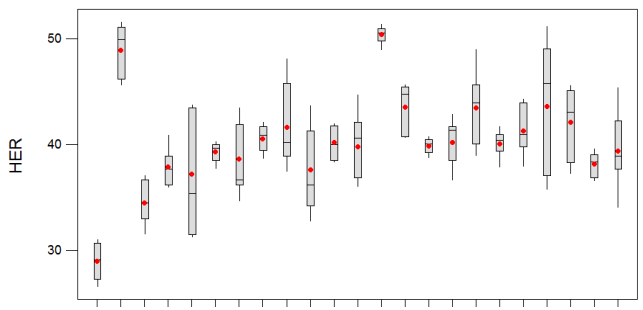


Failure by global formability





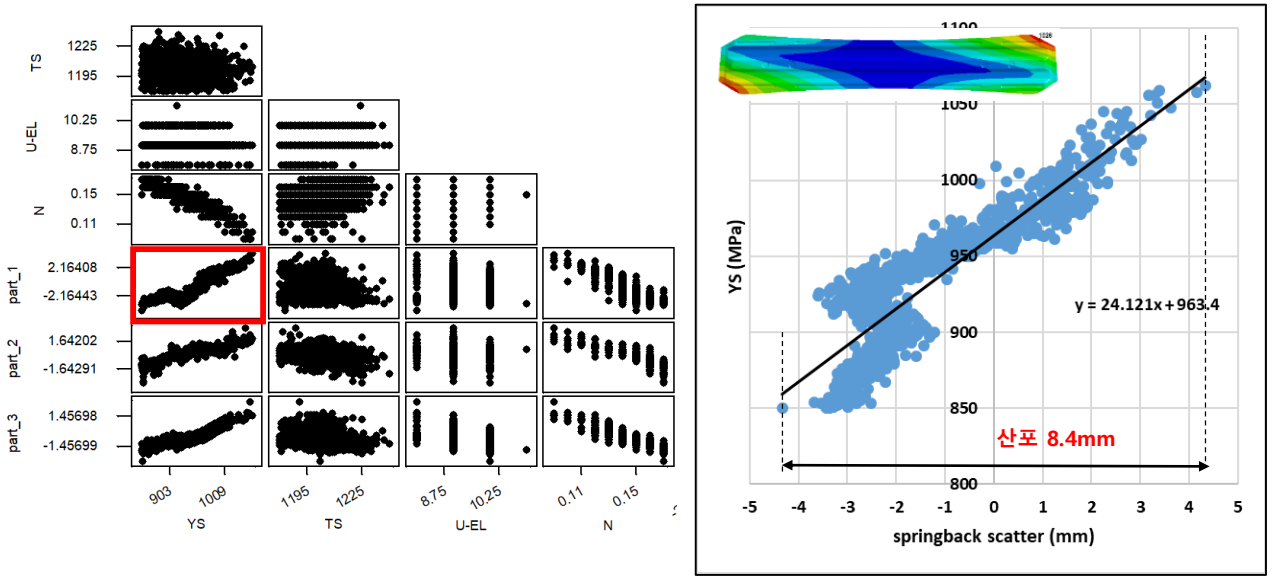




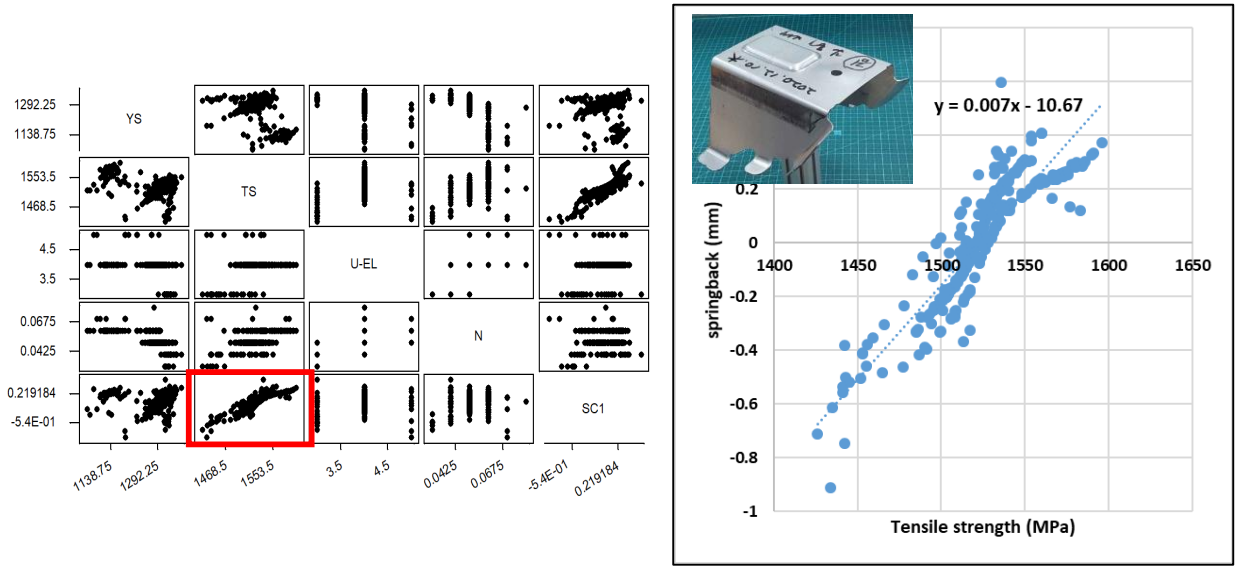
Failure by local formability

Material Scatter

- Material scatter vs. Springback
  - Yield strength vs. Tensile strength



Springback vs. Yield strength

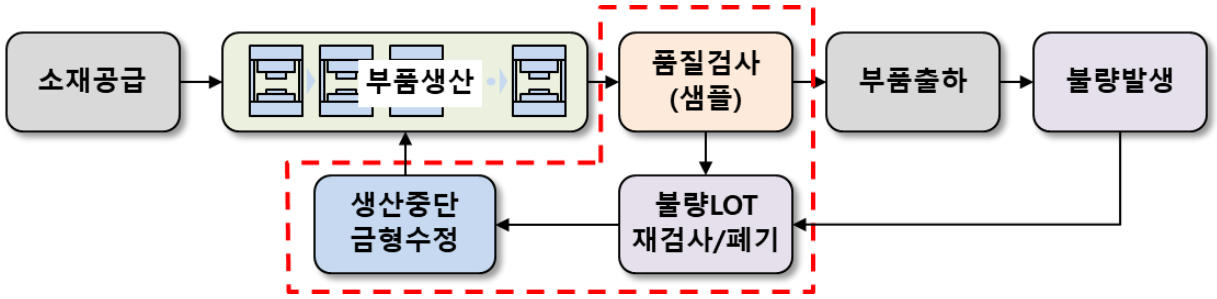


Springback vs. Tensile strength

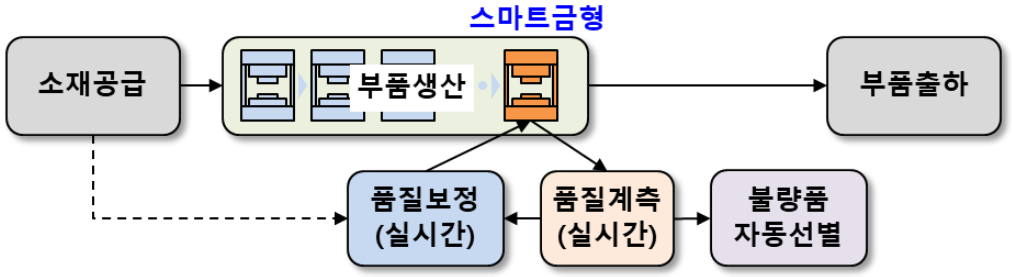
Smart Stamping Process

- Stamping process
  - Robustness vs. Flexibility
  - Human vs. Automatic inspection

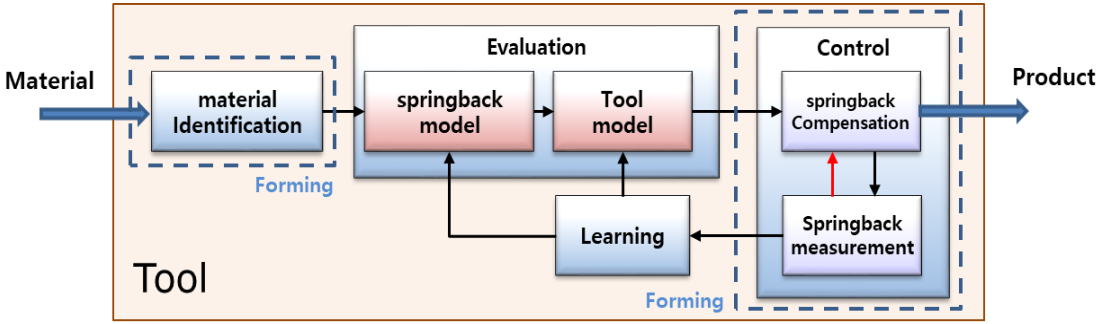
Conventional



Smart Stamping Process



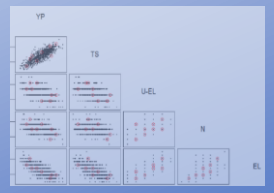
Smart Stamping Die



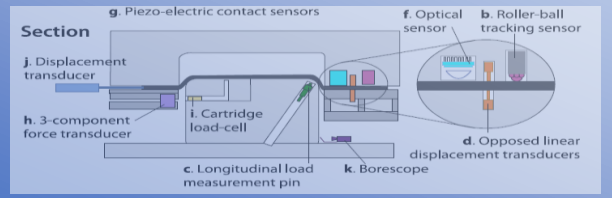
Smart Stamping Process

- **Technology Requirement**

Scatter Analysis
- statistic / qualitative / quantitative analysis
- material model, simulation time, accuracy



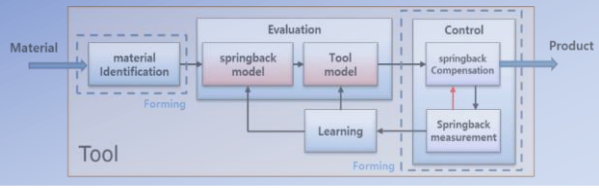
Quality Monitoring
- definition of product quality (online CF)
- selection of sensor type, position, number, etc



DESIGN | CHECK | SMART DIE | ACT | KEEP

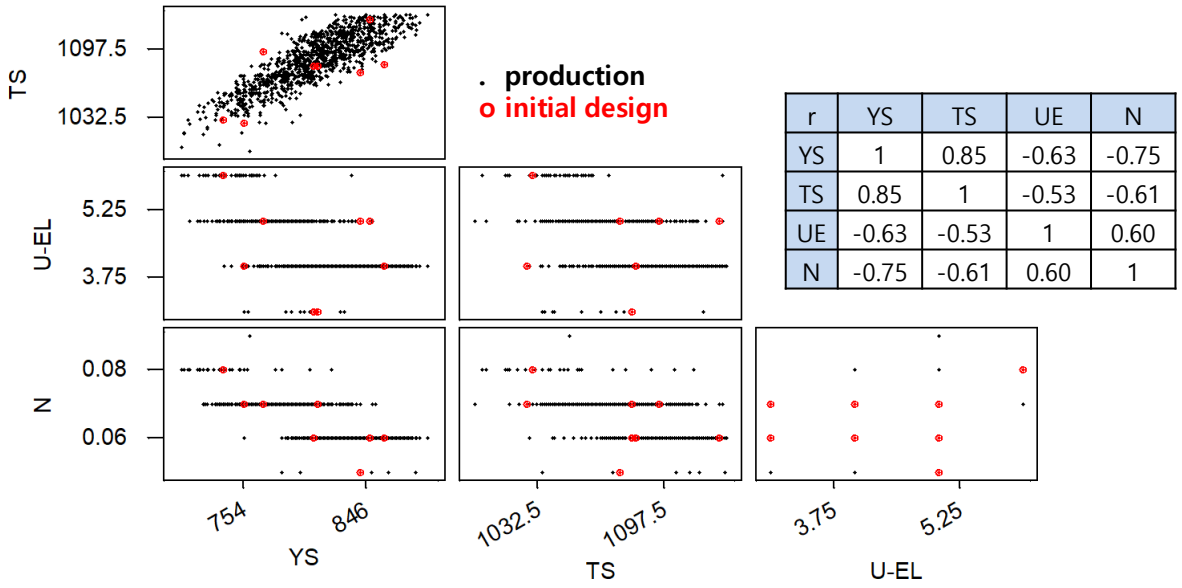
Quality Compensation
- mechanism to remedy quality error
- simple, low power, low cost, robust

Control Strategy
- feedback/feedforward control (PID/model/AI)
- Failure scenario, etc.



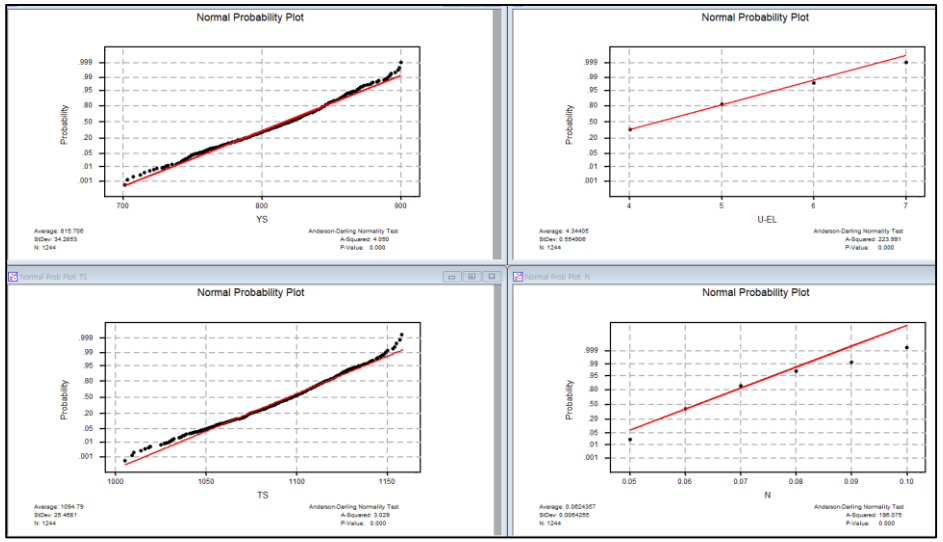
Technology - Scatter Analysis

- Modeling of Material variation
  - Key factor: Time / Accuracy
  - Production record vs. Statistical approach based on (μ, σ)
  - Full simulation vs. Selective simulation



r	YS	TS	UE	N
YS	1	0.85	-0.63	-0.75
TS	0.85	1	-0.53	-0.61
UE	-0.63	-0.53	1	0.60
N	-0.75	-0.61	0.60	1

correlation

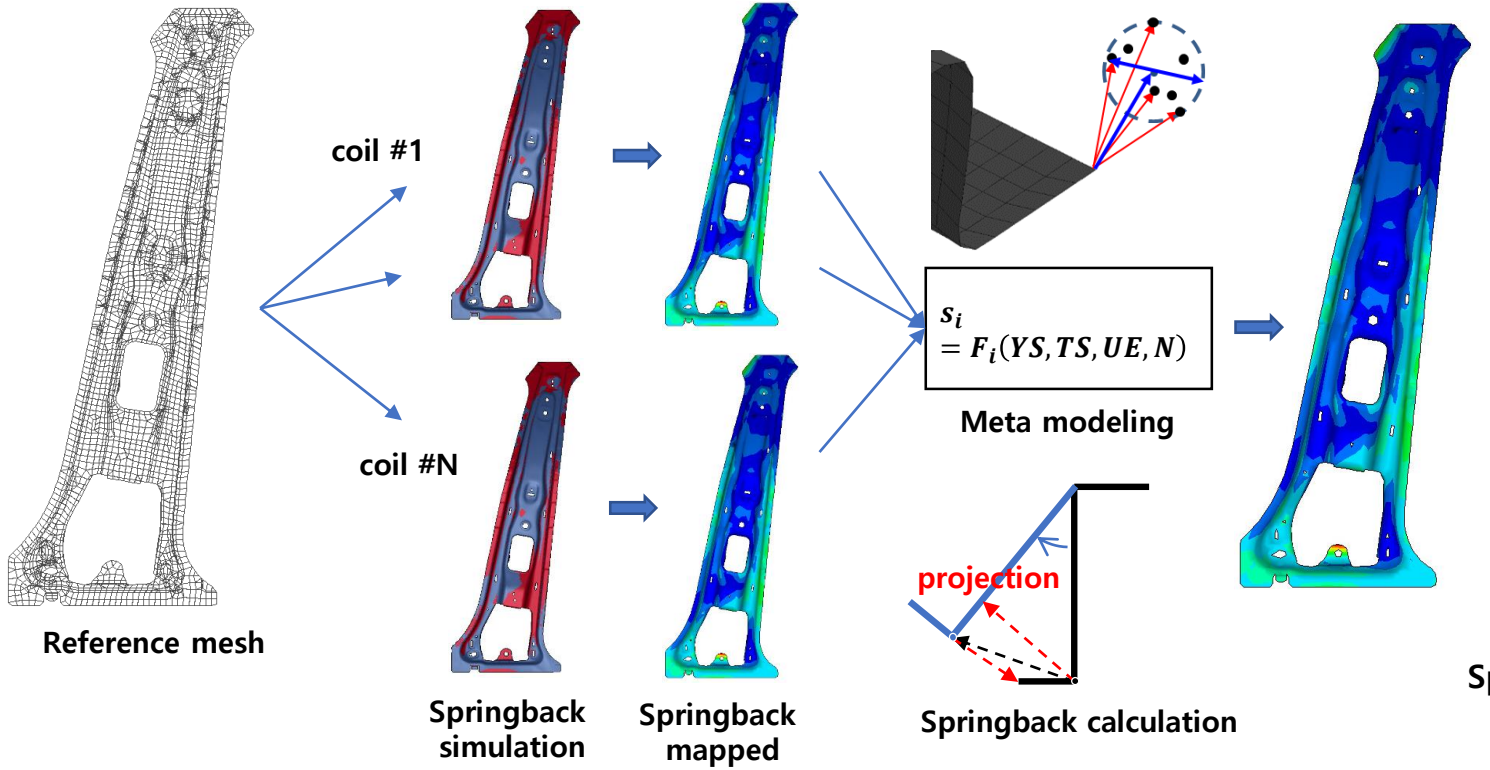


Normality test

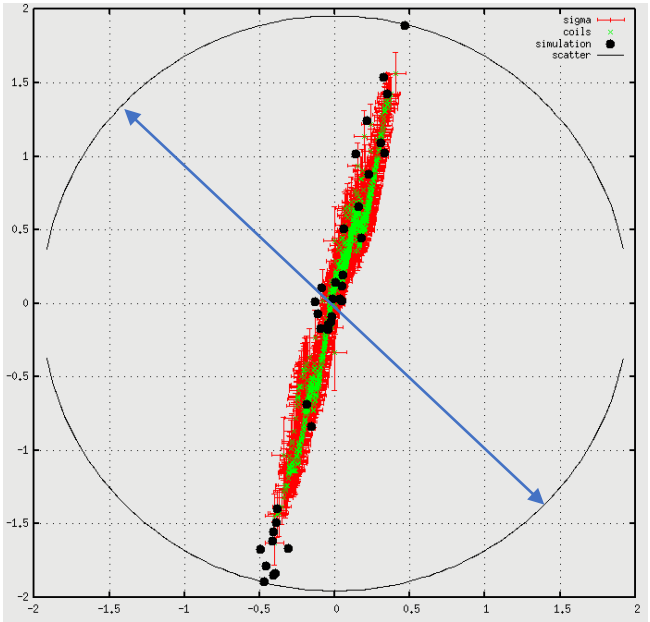
Material distribution (TS 980MPa / 1054 coils)

Technology - Scatter Analysis

- Modeling of Material variation
  - Quality aggregate vs. Quality function (meta modeling)
  - Accuracy Improvement



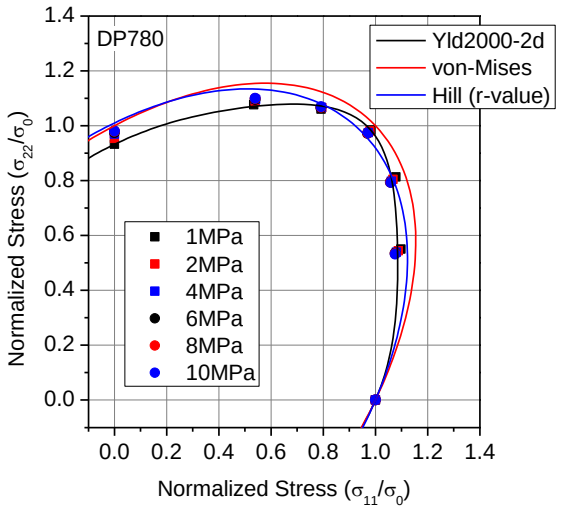
Quality function Approach



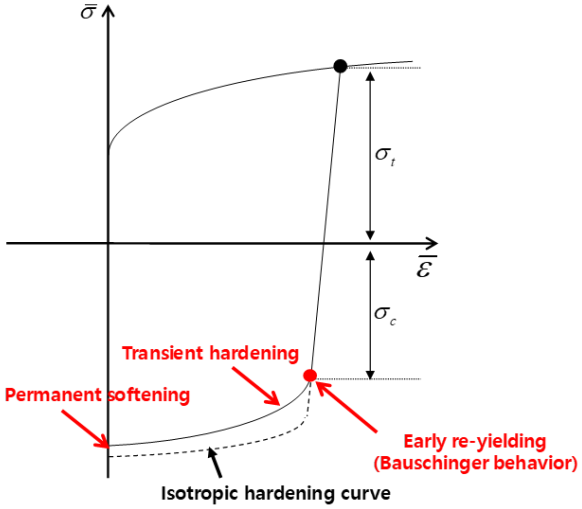
Springback prediction for all material distribution

Technology - Scatter Analysis

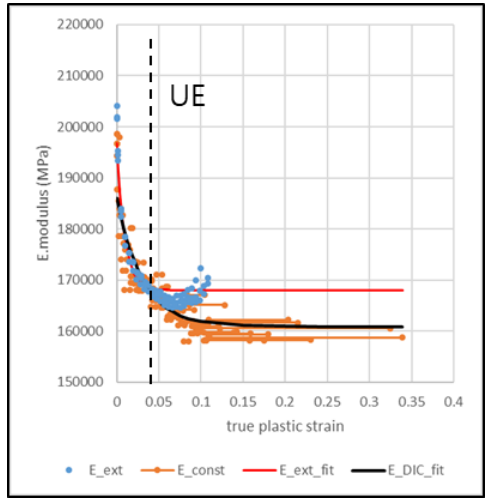
- **Material modeling**
  - **Yield function:** von Mises, Tresca, Hill48, Yld89, Yld96, Yld2000-2d, Corus-Vegter, etc
  - **Flow curve:** Swift, Voce, Hockett-Sherby, combined
  - **Kinematic model:** isotropic, Chaboche, Yoshida-Uemori, POSCO-HAH, etc
  - **Elastic modulus:** E0, Chord modulus, QPE, multi-surface model, DIC method, etc
  - **Friction model:** constant, pressure-dependent, velocity-dependent
  - **Formability:** FLD(strain based, stress based), Edge crack, Bending crack, Fracture



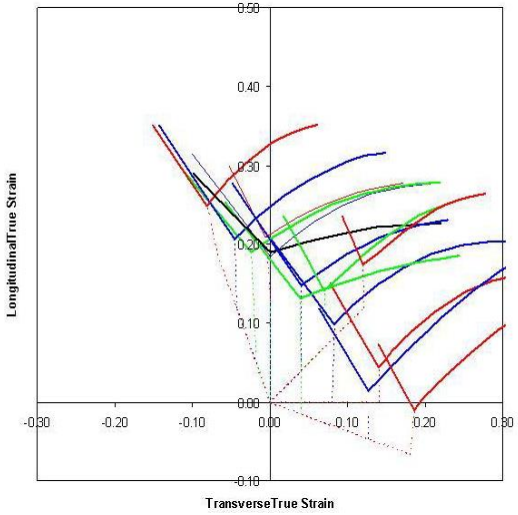
Yield function



Tension-compression



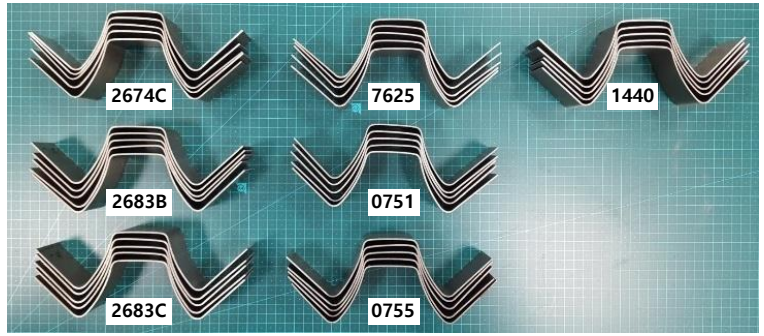
Elastic moduls for high strain

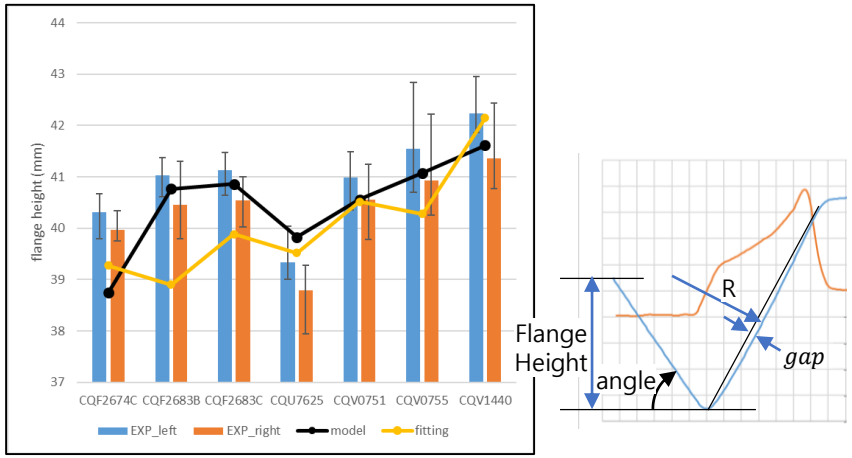


Path dependency of FLC

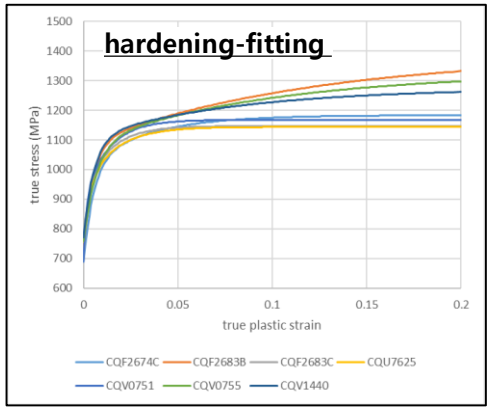
Technology - Scatter Analysis

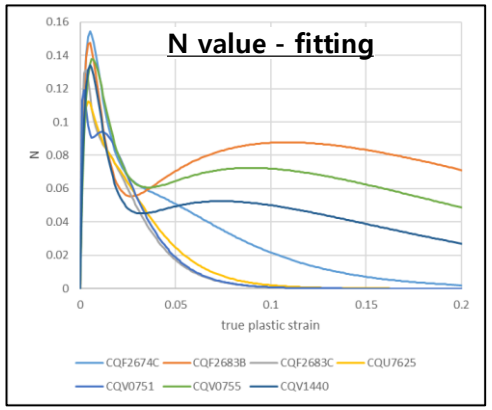
- **Material modeling**
  - **Consistency in the material model**

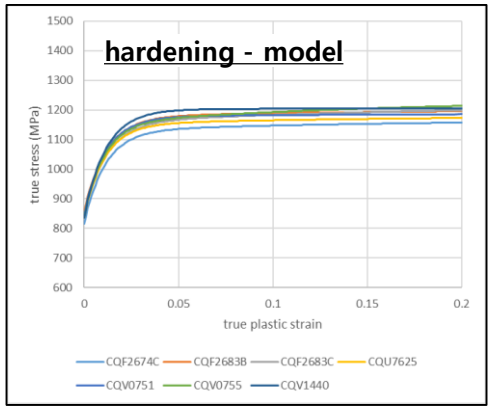


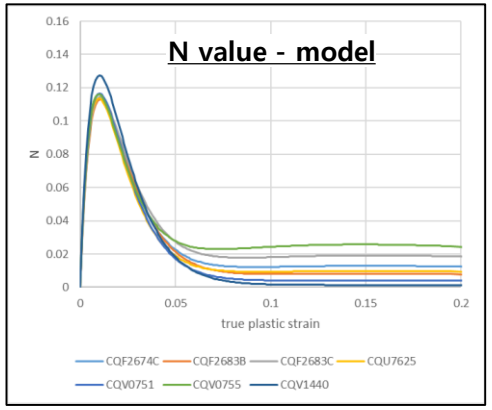


HAT springback test (980DP)





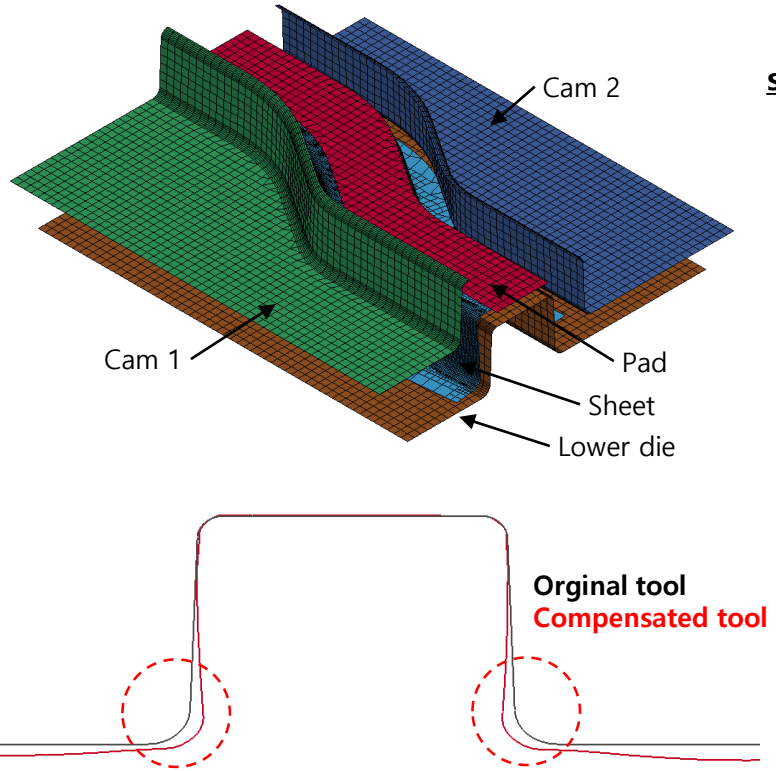




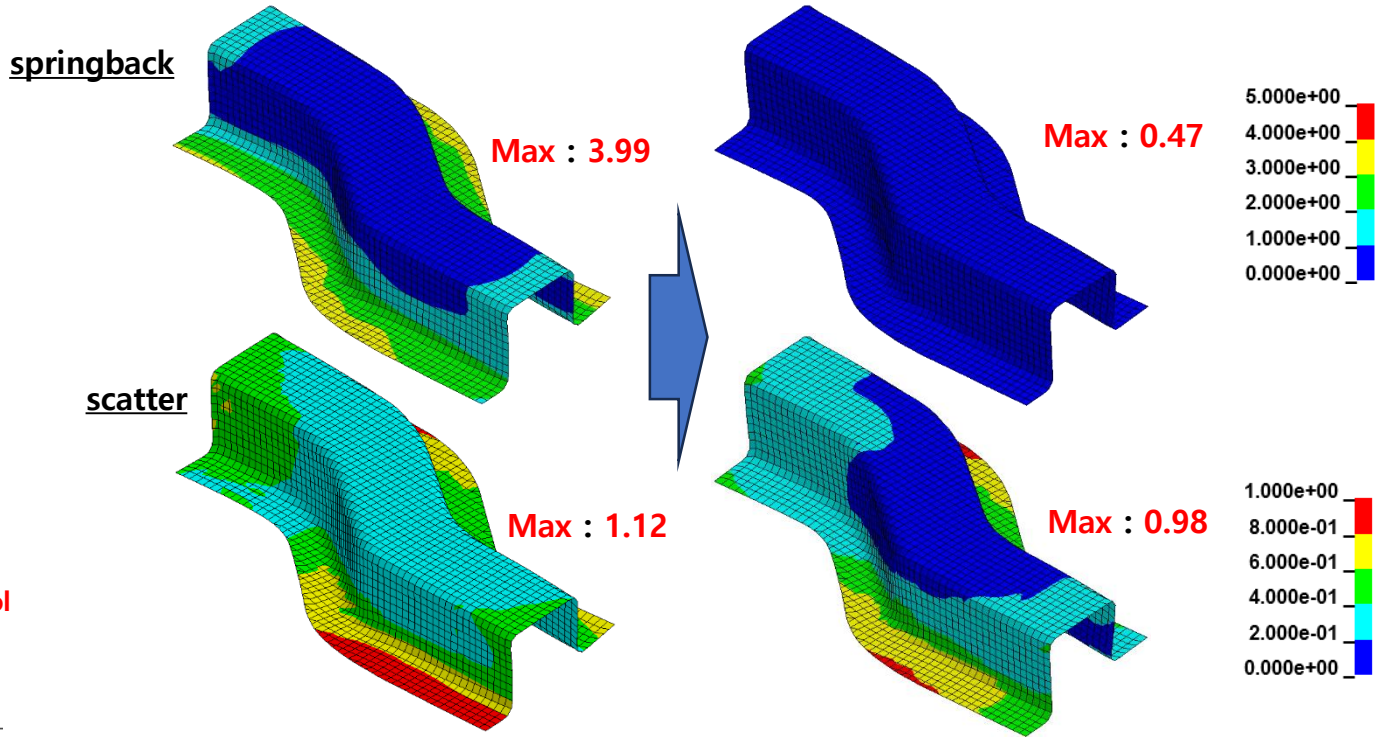
Material modeling variation

Technology - Scatter Analysis

- **Die build**
  - **Die surface compensation**



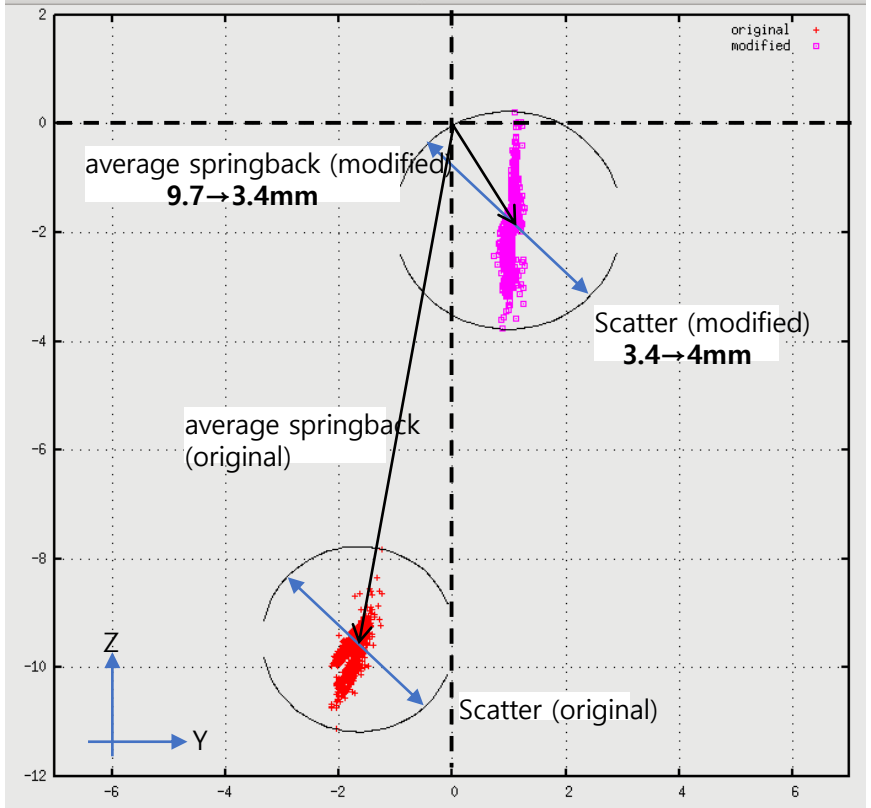
Die surface compensation



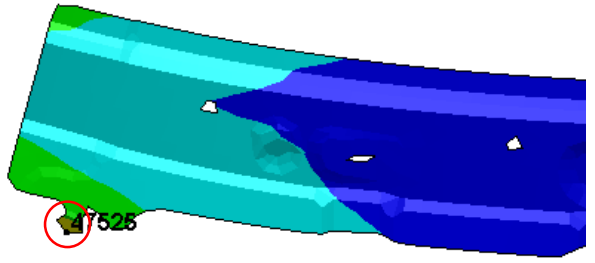
Springback change

Technology - Scatter Analysis

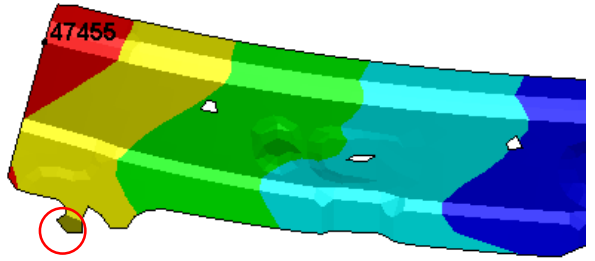
- **Die build**
  - **Die surface compensation vs. springback scatter**



Scatter (original)



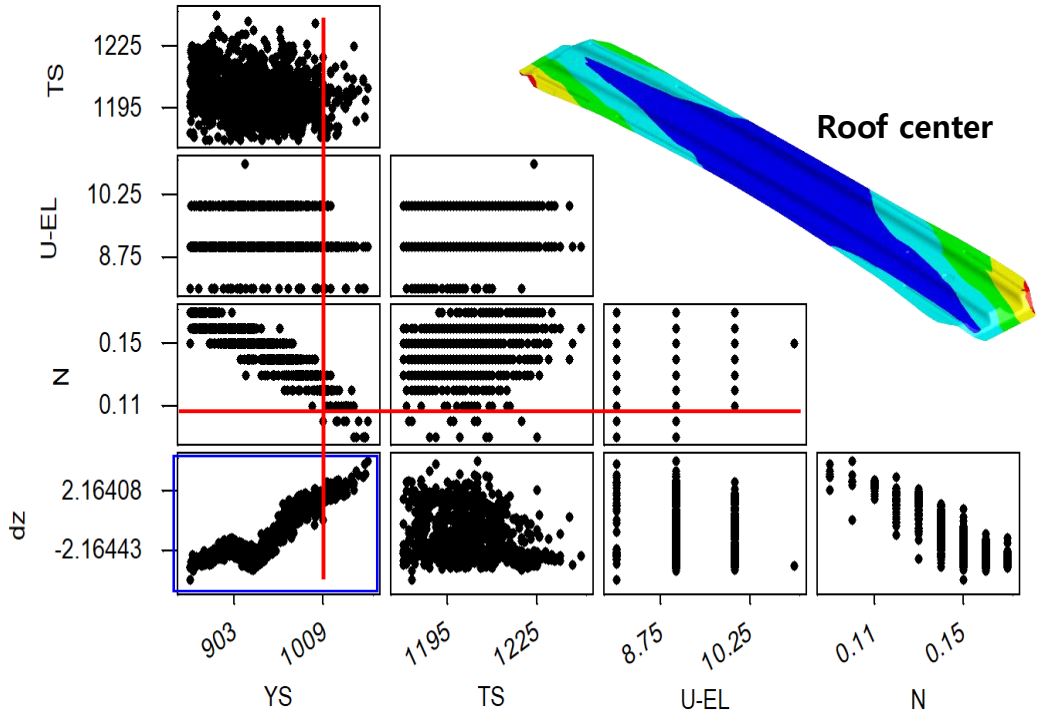
Scatter (modified)



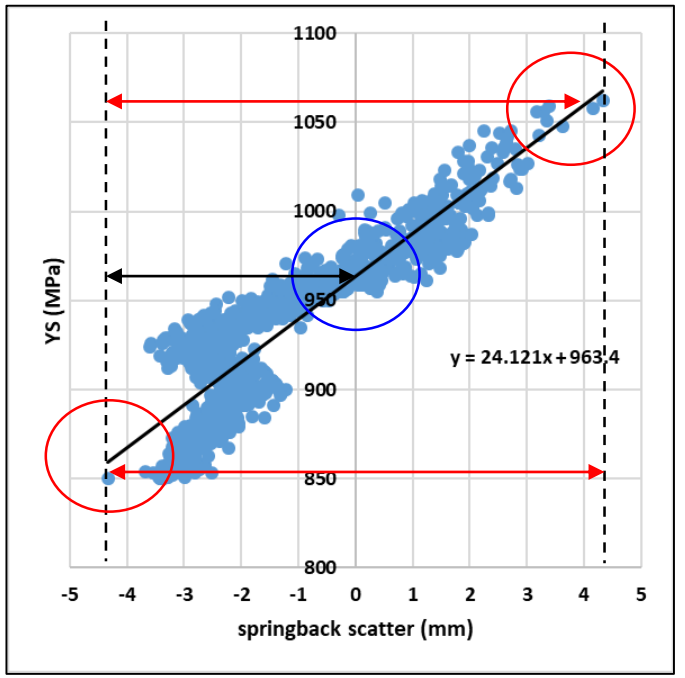
Effect of die surface compensation

Technology - Scatter Analysis

- **Die build**
  - **Worst vs. Average material**



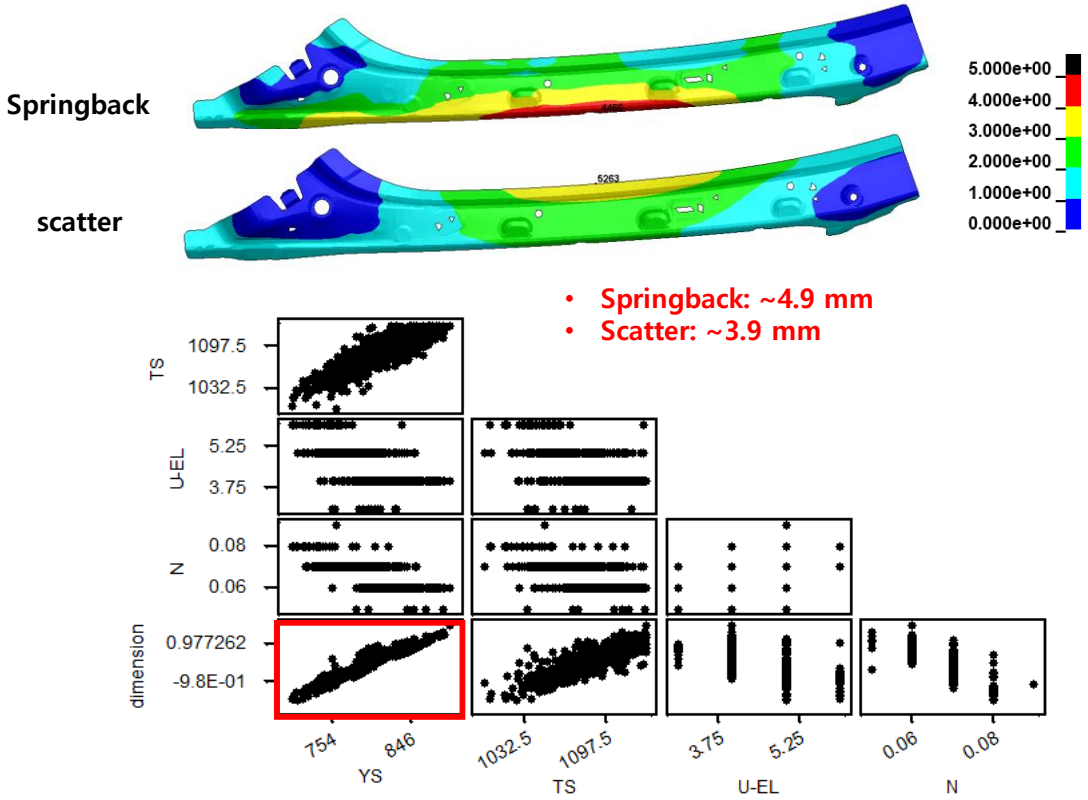
Springback scatter (mm)



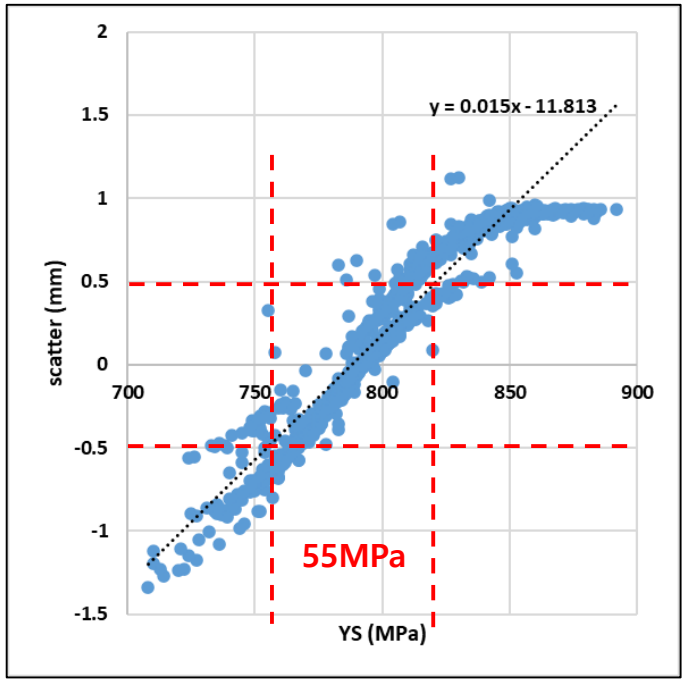
YS vs scatter

Technology - Scatter Analysis

- **Die build**
  - **Optimal tool design → Tool modification → Material coordination**



- Springback: ~4.9 mm
- Scatter: ~3.9 mm



springback scatter vs. Yield strength

※ Material guideline
YS : 65MPa
TS : 53MPa

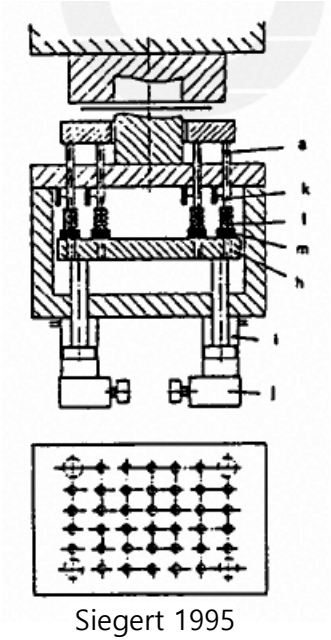
Technology - Monitoring / Compensation

- **Sensor**
  - **Product quality : Thinning, Necking, Crack, Wrinkle, Dimension, etc.**
  - **Direct vs. Indirect**

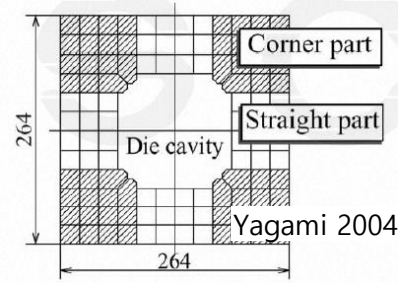
Product quality	Direct	In-direct
Dimension deviation Thinning Draw-in	touch displacement sensor, laser sensor profile sensor, roller sensor	Eddy current sensor Electromagnetic sensor Ultrasonic sensor
Necking	Profile sensor	Image: camera
Crack (punching tool failure)	Profile sensor	Image: camera Force: piezoelectric sensor, Load cell piezoelectric bolt Light: optical sensor Sound: sound sensor

Technology - Monitoring / Compensation

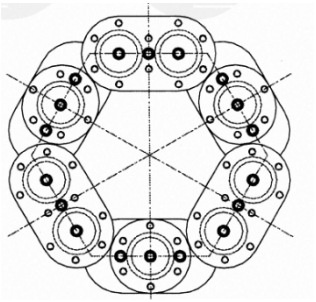
- **Actuator / How to correct the product quality deviation**
  - **Global vs. Local compensation or in-PRESS vs. in-DIE**
  - **Real time vs. Part-to-part compensation**
  - **Active vs. Passive approach**
  - **Power source (Electric / Pneumatic / Hydraulic)**



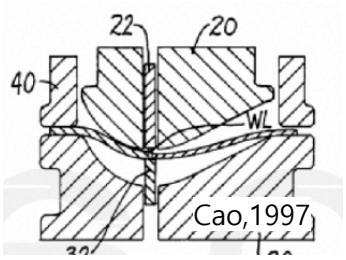
Siegert 1995



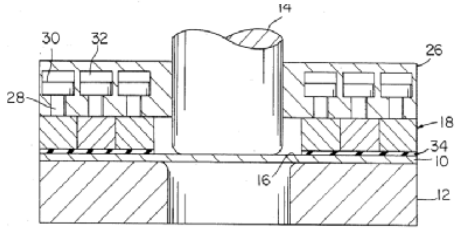
Yagami 2004



Cherrill 1998

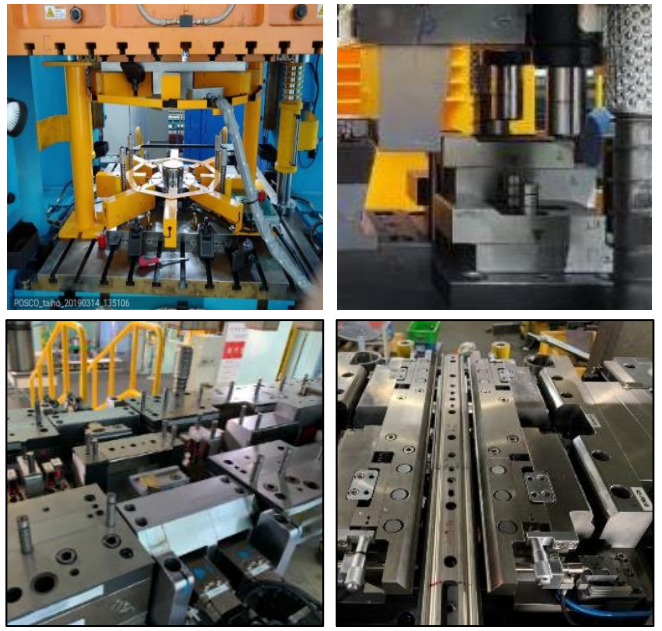


Cao,1997



Story 1988

Blank holding mechanism



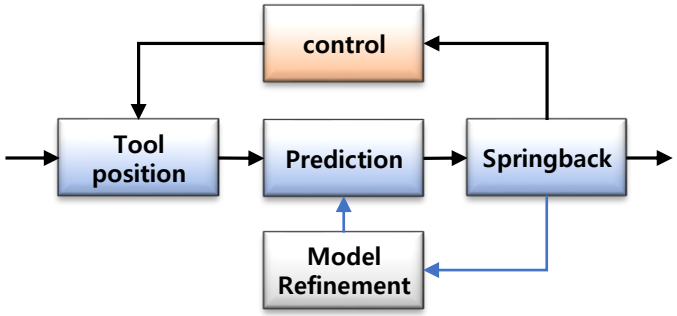
In-Die mechanism

Technology - Monitoring / Compensation

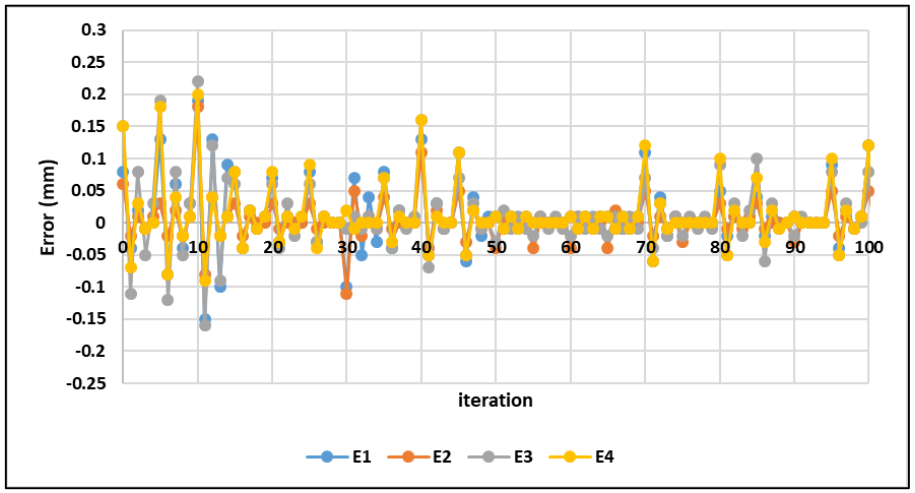
	Environment	COST	SPACE
	▪ Noisy / Dirty ▪ Harsh vibration	▪ Low cost	▪ Crowded ▪ Narrow space
SENSOR 	✓ Easy connection ✓ Robust ✓ Protected ✓ Easy replacement ✓ Precision: 10㎛ ✓ Displacement: 1mm	✓ Cheap ✓ Long lifetime ✓ General purpose ✓ FA Standard	✓ Small size ✓ Simple connection ✓ Small Transducer ✓ Modularization
ACTUATOR 	✓ Easy connection ✓ Robust ✓ Precision: 10㎛ ✓ Stroke: 1~2mm ✓ Load: ~100Tonf	✓ Cheap ✓ Low power ✓ Long operating time ✓ Minimum function (position)	✓ Small size ✓ Simple connection ✓ Small driver ✓ Modularization

Technology - Control

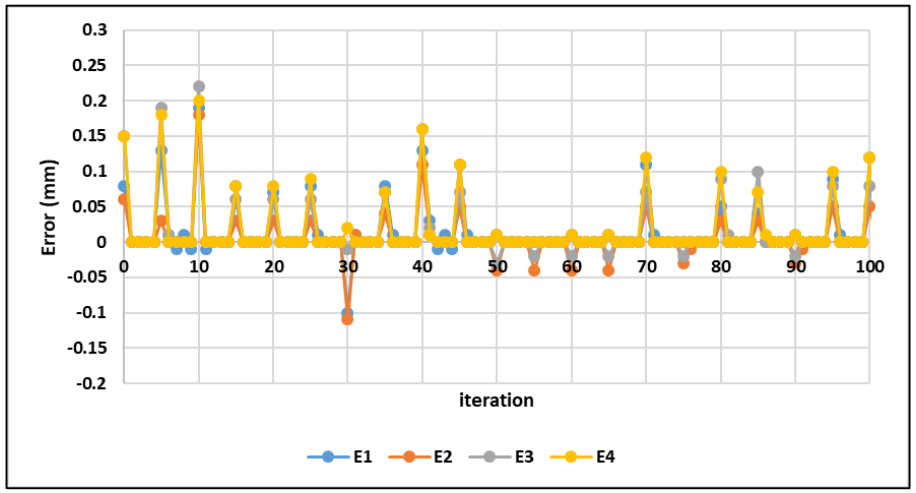
- Control scheme
  - Connection between Product Quality deviation and Tool Configuration
  - PID, Model based, AI
  - Feedback control vs. Feedforward control
- Optimization of control parameter
  - Theoretical vs. Simulation approach
  - Optimal parameter for material scatter



Process model (springback)



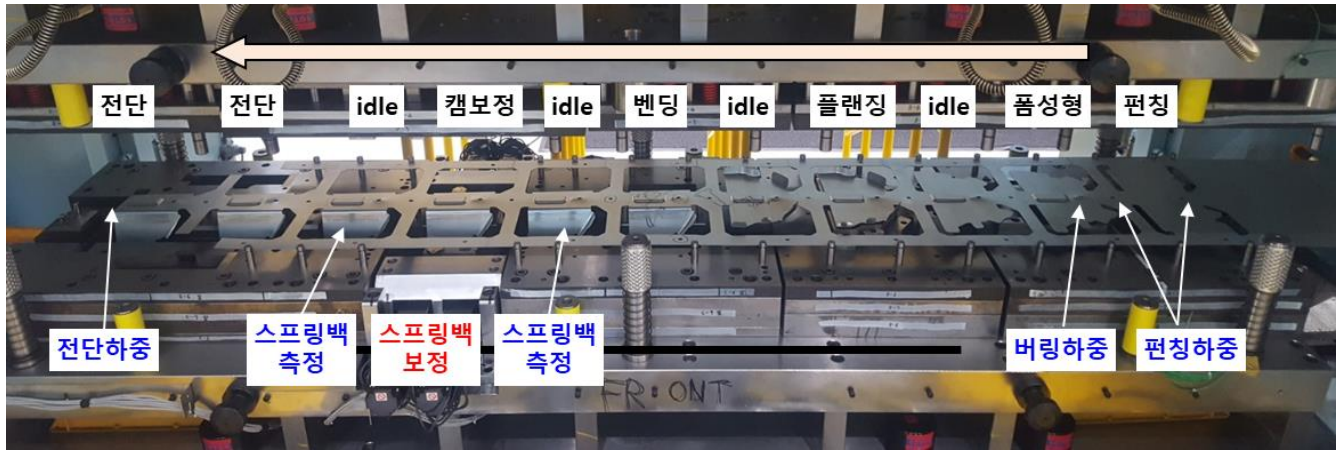
Process model (initial control parameter)



Process model (optimized control parameter)

Example

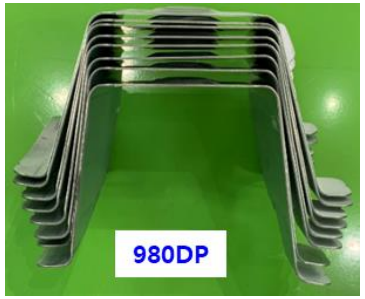
- Seat cross member (TS 980~1500MPa)

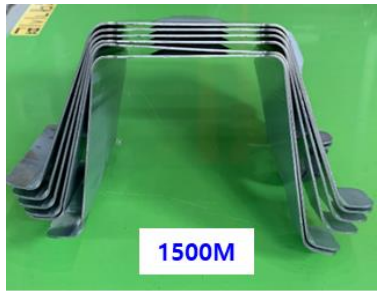


Progressve die

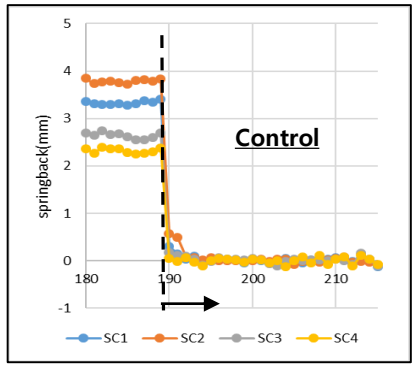
Quality sensor

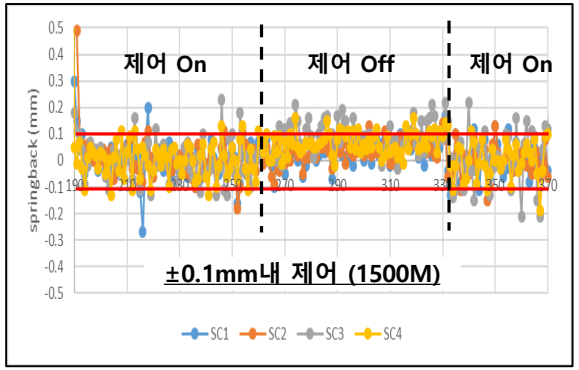
Compensation module



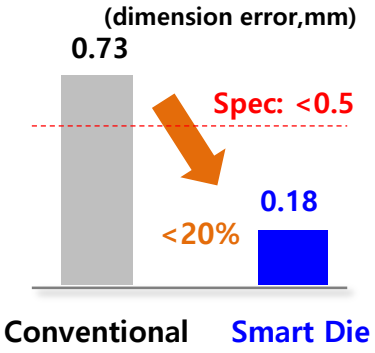


Springback scatter



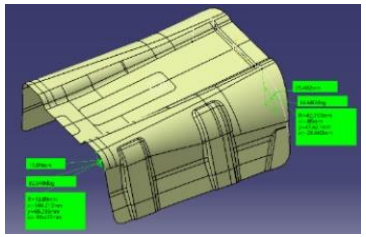


Control effect

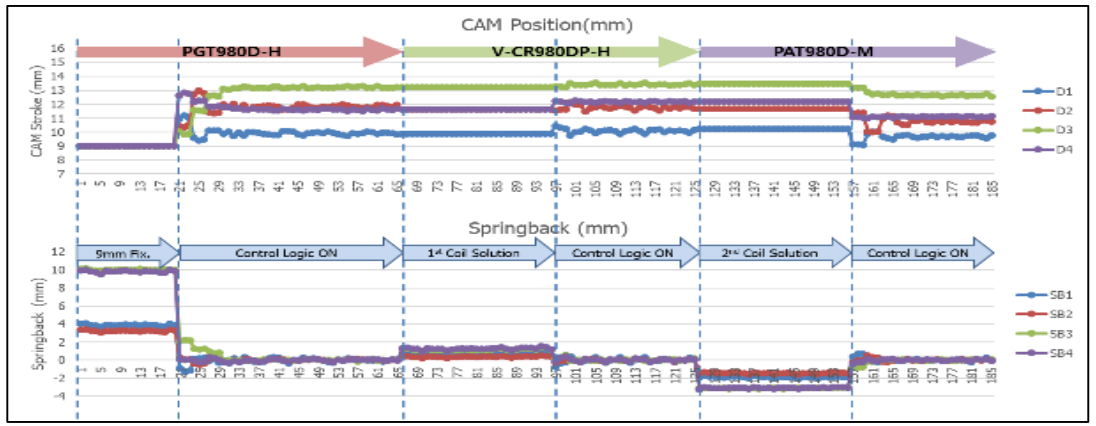


Example

- **Dash Lower (TS 980MPa)**
  - Laser sensor / CAM Punch

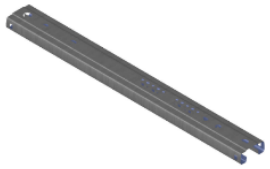


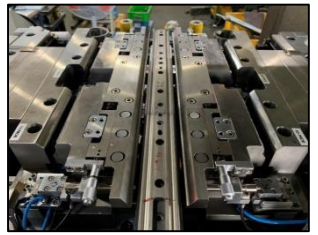
Springback scatter



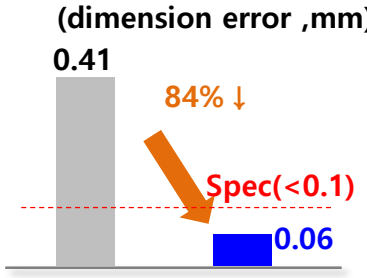
Production test

- **Seat Rail (TS 980MPa)**
  - Touch sensor / CAM Punch



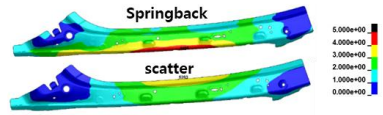


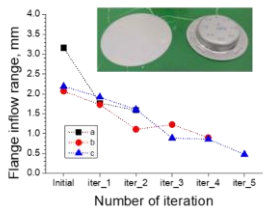
Smart Dies



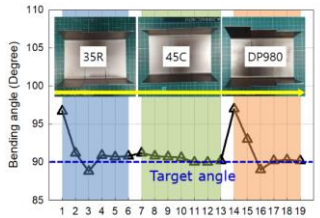
conventional Smart tool

- **Others**

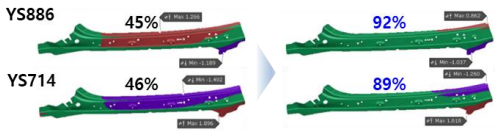




Draw-in



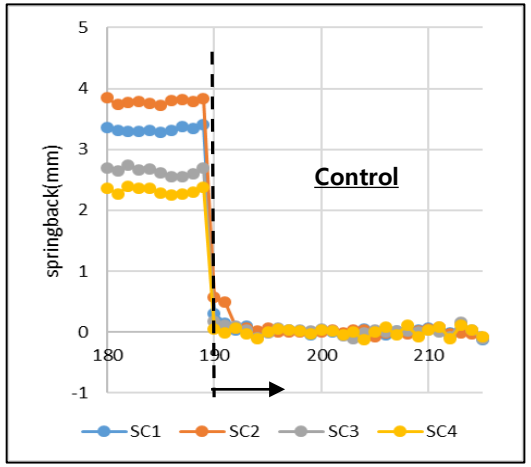
Flange angle

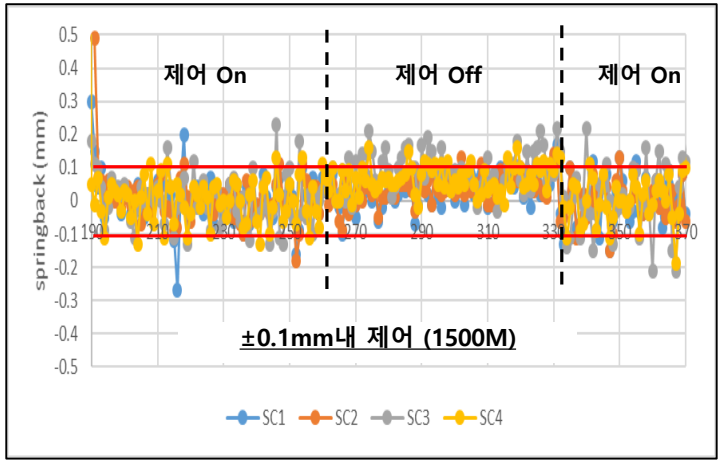


Twist

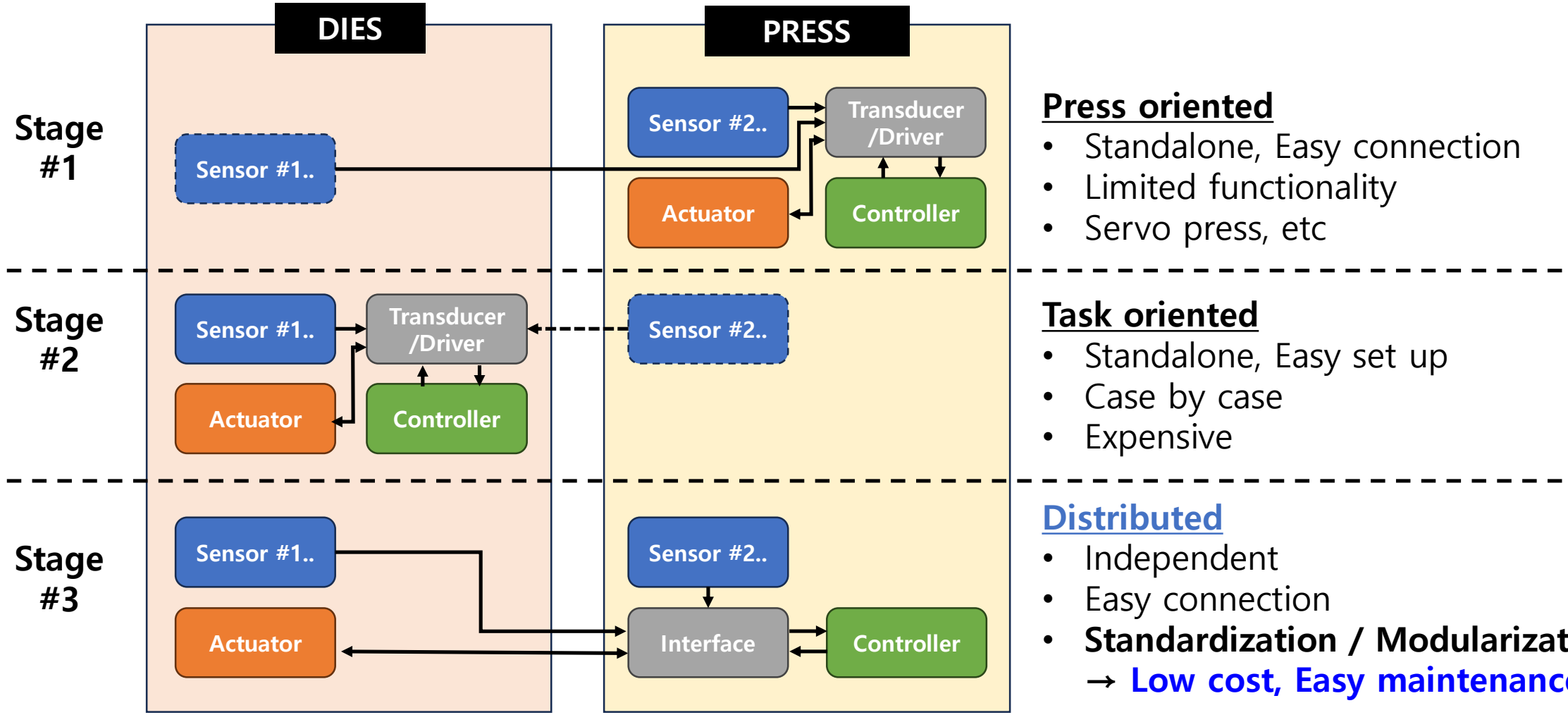
Example

- Advantages
  - Real time quality monitoring
  - Real time quality control by compensation mechanism
  - Robust against variations in materials, processes, and external factors.
  - No need for high-cost equipment investments (Smart stamping dies)
- Disadvantages
  - Cost increase : Die build cost vs. Product quality maintenance cost
  - Lack of Experience : scatter simulation, die design, control system maintenance
  - Resistance of operators





Future : Distribution of Intelligence



Press oriented

- Standalone, Easy connection
- Limited functionality
- Servo press, etc

Task oriented

- Standalone, Easy set up
- Case by case
- Expensive

Distributed

- Independent
- Easy connection
- **Standardization / Modularization**
  → **Low cost, Easy maintenance**

Summary

- 안전규제 강화 및 원가절감에 대한 고객사의 요구로 고강도강 채용이 늘고 있음
- 제품 품질편차를 줄이기 위해서는 설계단계부터 산포에 대한 분석 및 대응이 필요함
- 스마트 금형제어기술 적용시 실시간 품질보정 및 관리가 가능
- 다양한 부품 제조공정에 적용 가능하도록 표준화, 모듈화가 필요

소재-금형-생산업체간 기술협력을 통한 시장변화 도모