1

Billur
Engineering Quality Solutions

New Press-Hardening Grades and Process Enhancements for Hot Stamping

Dr. Eren Billur
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Dr. Danny Schaeffler
Engineering Quality Solutions, Inc., www.EQSgroup.com
ds@EQSgroup.com

2

Introduction to the Presenters

Eren Billur

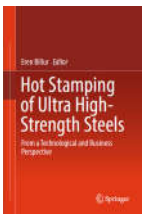
Primary Contributor to PHS Sections in AHSS Application Guidelines, AHSSinsights.org

Billur Makine (1989) - selling mechanical presses, progressive and transfer press lines.

- Core competence: Retrofitting old presses with modern control systems and automation.
- Market: mainly domestic, Turkey.

Billur Metal Form (2015) – offering engineering, consulting and training in sheet metal forming.

- Core competence: Press Hardening, Gen3 AHSS.
- Market: over 60% of the revenue is from USA, Germany, China and Japan. Member of automotive exporters association since 2017.
- **Writing MetalForming Magazine's Cutting Edge Column since 2019**



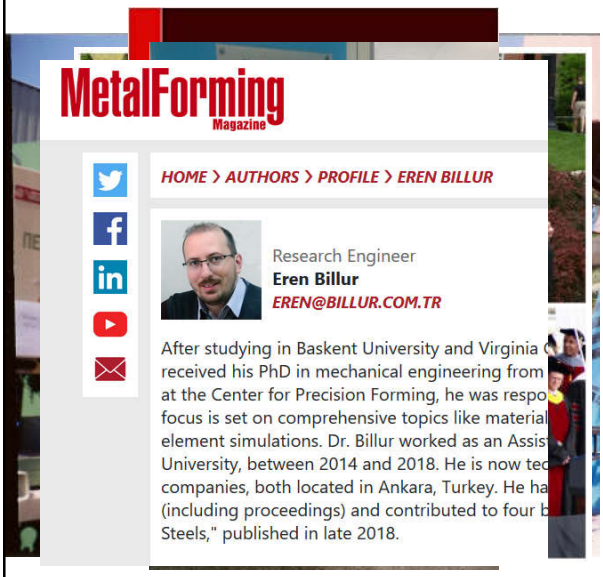
Danny Schaeffler

Technical Editor for Metallurgy and Forming, AHSS Application Guidelines, AHSSinsights.org

Engineering Quality Solutions (2002) - offering engineering, consulting and training in sheet metal forming.

- Core competence: providing product applications assistance to materials and manufacturing companies
- Focus – Hands-On: Materials selection/ optimization, tooling buyoff, field formability analyses, manufacturing process improvement, and cost savings / cost avoidance projects.
- Focus - Education: Teaching the fundamentals and practical details of material properties, forming technologies, processes, and troubleshooting needed to reliably form high quality components.
- Market: Global, primarily North America, Europe, and Asia
- **Writing MetalForming Magazine's Science of Forming / Metal Matters Column since 2017**

Introduction to presenters



Have been involved in sheet metal forming since 1989.

Moved to US in 2007 for MS and PhD in mechanical engineering

Completed PhD thesis on hot stamping in 2013 – which was later published as a book.

In 2015, established Billur Metal Form, which offers material characterization, simulation, training and consulting services.

Since 2020, authoring "Cutting Edge" column in Metalforming Magazine.

Outline

- **Main drivers for press hardening**
- Common PHS/PQS Grades
  - Low strength with high ductility grades for crash energy management
  - High strength for intrusion prevention and safety cage integrity
  - Techniques for tailored strength, stiffness, or energy absorption within a single part
- Emerging Grades and Technologies
- Typical Process Route
  - Recent Enhancements
- Warm and hot stamping of aluminum alloys
- Competition to press hardening

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Electrification

ICEV – Internal Combustion Engine (Petrol / Diesel). Currently the dominant one. Losing its dominance and share.

HEV or PHEV – (Plug-in) hybrid electric vehicle. Favored for longer range and higher efficiency. Requires both ICE and electric components, making them heavy and expensive.

Ref: Ibrovic et al 2021 (EuroCarBody, Volvo)

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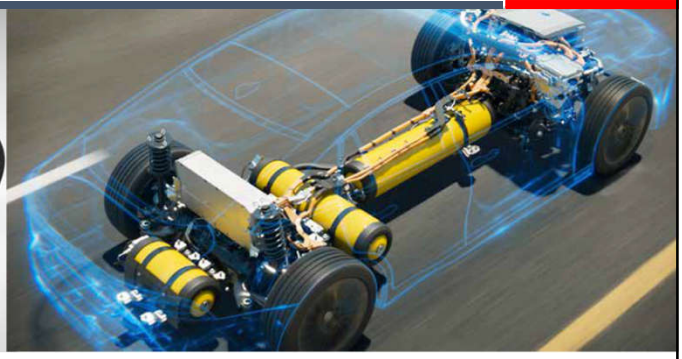
Electrification



BEV – Battery electric vehicles. Currently the most efficient powertrain. Range, charging infrastructure, battery supply, high cost slow down their rapid increase. Range extenders were tried but did not become successful.

FCEV – Fuel Cell Electric Vehicles. Currently only 3 OEM's offer 1 model each. (Green) Hydrogen production, infrastructure and car packaging are problems.

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Ref: Ibrovic et al 2021 (EuroCarBody, Volvo), Image google.

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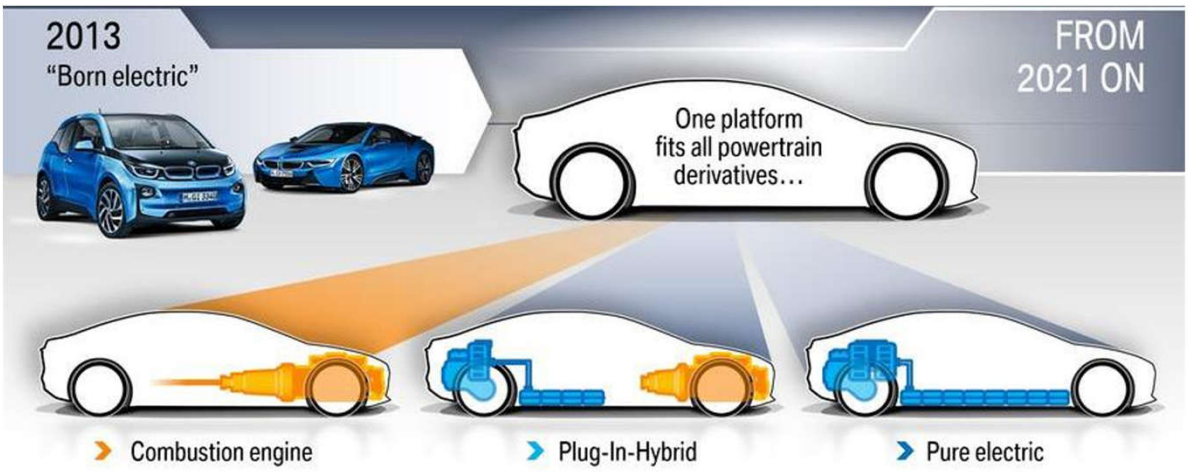
Two electrification strategies



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Ref: Baginski 2020 (BMW)

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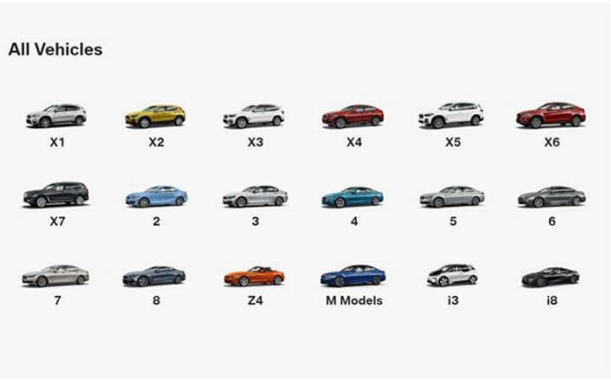
Separate EV Line-up



In 2021, you had 16 ICE models to choose in BMW.
Your only PHEV option was i8,
Your only BEV option was i3.

In 2022, if you want to buy a compact VW:
Your ICE option is Golf
Your BEV option is ID.3

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Choose your own powertrain

Volvo started XC40 production in 2017. This is a small SUV, available with 3- and 4-cylinder petrol and diesel engines.

1570 – 1770 kg
3460 – 3900 lbs

In 2019, the twin engine T5 recharge model is introduced. This is a Plug-in hybrid with 3-cylinder petrol engine and electric motor.
1810 kg (+240 kg on 3-cyl.)
3990 lbs (+530 lbs on 3-cyl.)

Since 2020, P8 Recharge is offered as a full electric car.

2030 – 2190 kg (+460 kg)
4475 – 4830 lbs

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Choose your own powertrain

	735i[1]	740i[1]	760i xDrive[1]	740d xDrive	750e xDrive	M760e xDrive	i7 xDrive60
Bauzeitraum	ab 11/2022			ab 03/2023			ab 11/2022
Motorart	Ottomotor			Dieselmotor	Ottomotor + Elektromotor		2 Elektromotoren
Motorbauart	R6		V8	R6			—
Gemischaufbereitung	Benzindirekteinspritzung			Common-Rail-Einspritzung	Benzindirekteinspritzung		—
Aufladung	Twin-Scroll-Turbolader		zwei Twin-Scroll-Turbolader	Twin-Scroll-Turbolader			—
Motortyp	BMW B58		BMW S68	BMW B57	BMW B58		—
Hubraum	2998 cm³		4395 cm³	2993 cm³	2998 cm³		—
max. Leistung bei 1/min	210 kW (286 PS)/ 5000–6500	280 kW (380 PS)/ 5200–6250	400 kW (544 PS)/ 5500	220 kW (299 PS)/ 4000	360 kW (489 PS)/ 5000–6500	420 kW (571 PS)/ 5200–6250	400 kW (544 PS)
max. Drehmoment bei 1/min	425 Nm/ 1750–4500	540 Nm/ 1850–5000	750 Nm/ 1800–5000	670 Nm/ 1750–3000	700 Nm/ 1750–4700	800 Nm/ 5000	745 Nm
Getriebe, serienmäßig	8-Stufen-Automatikgetriebe[2]						Zweistufiges Ein-Gang-Getriebe
Antrieb, serienmäßig	Hinterradantrieb		Allradantrieb xDrive				Elektrischer Allradantrieb xDrive
Leergewicht nach EU in kg	2150	2165	2345	2255	2455	2525	2715

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https://de.wikipedia.org/wiki/BMW_G70

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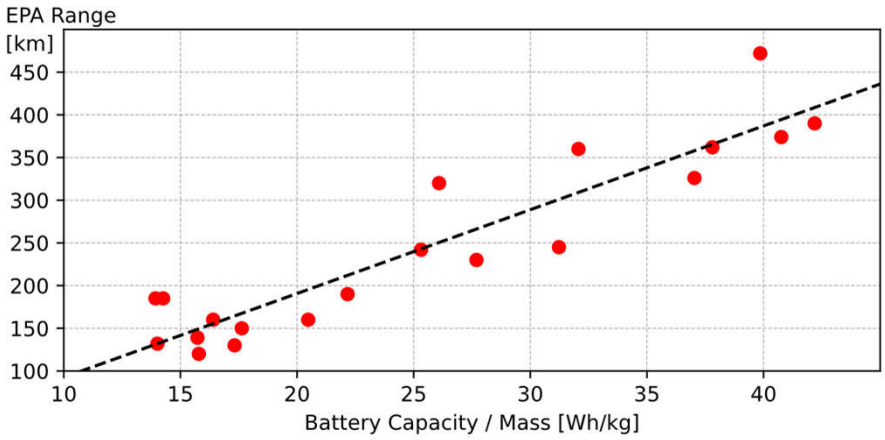
EV Weight Spiral

More PHS or Hot Formed Al Required



- Longer range requires larger capacity battery
- Larger capacity batteries weigh more
- Chassis, brakes and the body have to be modified
- More mass introduced reduces the range

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Own work

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Several EV Weight Problems in EU

Without a commercial license you can only drive:
8 passengers + 1 driver
3,500 kg (7,700 lbs) GVW

Since 2019 the limit is revised to 4,250 kg (9,400 lbs) only for Alternative Fuel Vehicles.

Mercedes-Benz eSprinter has two versions:

Battery [kWh]	Range	Payload
41	120 km / 75 mi	1,045 kg / 2,300 lbs
55	168 km / 105 mi	891 kg / 1,960 lbs

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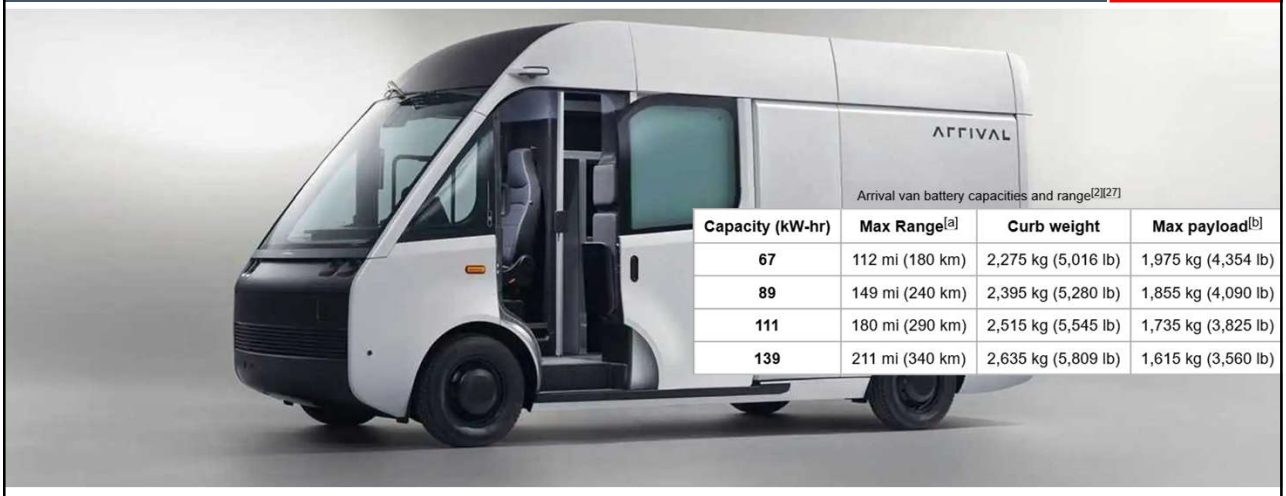
Several EV Weight Problems in EU



Arrival van battery capacities and range[2][27]

Capacity (kW-hr)	Max Range[a]	Curb weight	Max payload[b]
67	112 mi (180 km)	2,275 kg (5,016 lb)	1,975 kg (4,354 lb)
89	149 mi (240 km)	2,395 kg (5,280 lb)	1,855 kg (4,090 lb)
111	180 mi (290 km)	2,515 kg (5,545 lb)	1,735 kg (3,825 lb)
139	211 mi (340 km)	2,635 kg (5,809 lb)	1,615 kg (3,560 lb)

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Heavier cars – IIHS Roof Strength

Peak Force = 19,949 lbs (9,057 kgf)

Weight = 3,811 lbs (1730 kg)

SWR = 5.23 > 4.00 Good

Summary:
17% higher peak force
7% less SWR

Peak Force = 23,312 lbs (10,583 kgf)

Weight = 4,787 lbs (2170 kg)

SWR = 4.87 > 4.00 Good

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Videos from: IIHS YouTube Channel; Edited and sped up.

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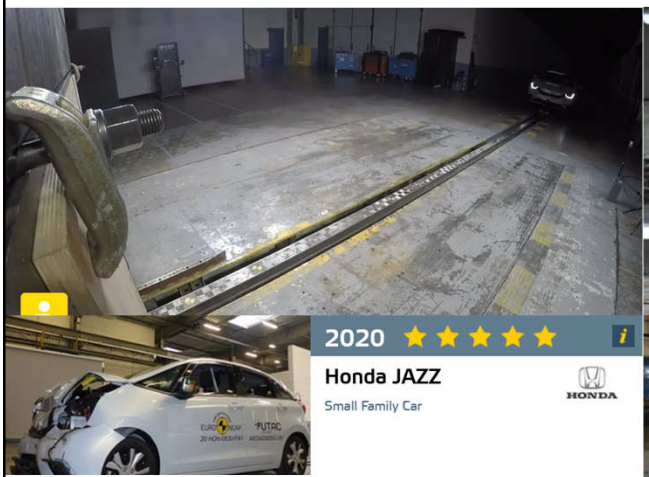
Heavier cars – EuroNCAP Full Frontal



2020 ★★★★★

Honda JAZZ

Small Family Car

HONDA

2020 ★★★★☆

Honda e

Small Family Car

HONDA

More PHS or Hot Formed Al Required

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EuroNCAP Web Page; Videos are edited for the presentation.

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New crash requirements

Billur Engineering Quality Solutions

Side Impact Crashworthiness Evaluation 2.0
Crash Test Protocol
Version II
October 2022

Years	Pre-2020	Post-2020	
Speed	50	60	km/h
	31.3	37.5	MPH
Mass	1,300	1,400	kg
	2,860	3,080	lbs
Energy	125	194	kJ
	100%	155%	

More PHS or Hot Formed Al Required

Years	Pre-2021	Post-2021	
Speed	50	60	km/h
	31.3	37.5	MPH
Mass	1,500	1,900	kg
	3,300	4,185	lbs
Energy	145	264	kJ
	100%	182%	

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Antoine and Touron 2021, Wendekamm 2022, IIHS Web Page

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New crash requirements

Billur Engineering Quality Solutions

A small EV in Europe
(Similar size of Honda Fit or Ford Fiesta HB in US)

2013 ★★★★★
Renault ZOE
Supermini
✕ Rating Expired

2021 ☆☆☆☆☆
Renault Zoe
Supermini

More PHS or Hot Formed Al Required

Ref: EuroNCAP web page

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New crash requirements

2022 Chevrolet Malibu

MIDSIZE CAR / 4-DOOR SEDAN

Crashworthiness	
Small overlap front: driver-side	G
Moderate overlap front	G
Side: original test	G
Side: updated test	P
Roof strength	G
Head restraints & seats	G

More PHS or Hot Formed Al Required

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Ref: IIHS Web page.

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Updated moderate overlap test!

2023 Jeep Grand Cherokee L

MIDSIZE SUV / 4-DOOR SUV

Award applies only to vehicles built after May 2023

Crashworthiness	
Small overlap front: driver-side	G
Small overlap front: passenger-side	G
Moderate overlap front: original test	G
Moderate overlap front: updated test	P
Side: updated test	G

More PHS or Hot Formed Al Required

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Ref: IIHS Web page.

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Outline

- Main drivers for press hardening
- **Common PHS/PQS Grades**
  - Low strength with high ductility grades for crash energy management
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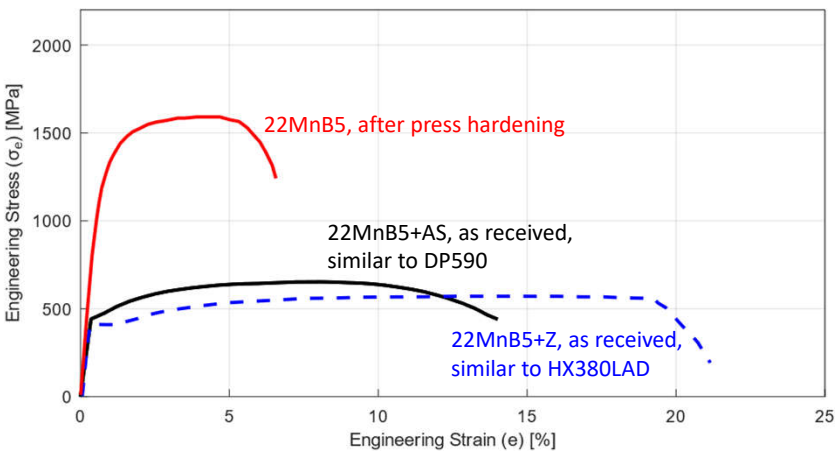
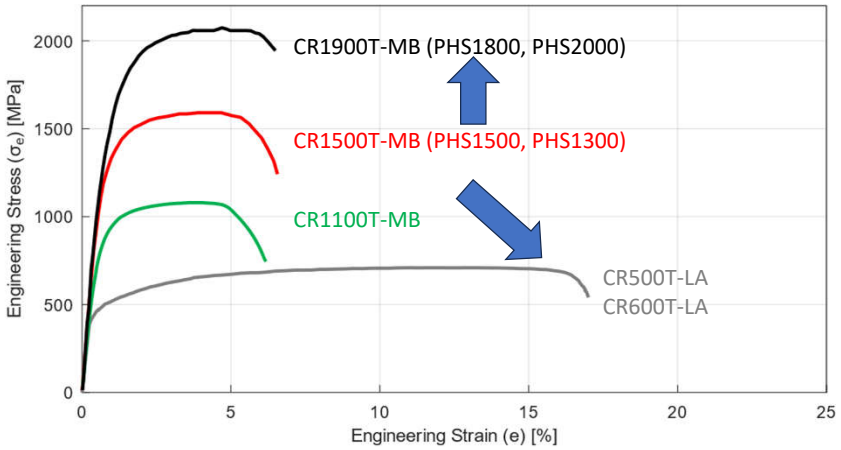
"The" PHS Grade: 22MnB5 – PHS1500



22

Two improvements over 22MnB5



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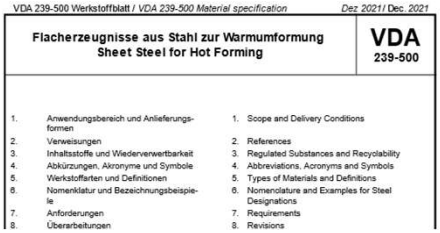
Commercial Availability

VDA 239-500	ArcelorMittal	BaoSteel	posco	SSAB	ThyssenKrupp	voestalpine
CR500T-LA	Ductibor 450	B500 HS	-	-	MBW 500	phs-ultraform 490
CR600T-LA	Ductibor 500	B600 HS	-	-	MBW 600	-
CR1100T-MB	Ductibor 1000	B1200 HS	-	-	MBW 1200	-
CR1500T-MB	Usibor 1500	B1500 HS	PCT1470H	Docol PHS 1500	MBW 1500	phs-ultraform 1500
CR1900T-MB	Usibor 2000	B1800 HS	-	Docol PHS 2000	MBW 1900	phs-ultraform 2000


VDA 239-500 Werkstoffblatt / *VDA 239-500 Material specification* *Dez 2021 / Dec. 2021*

Flacherzeugnisse aus Stahl zur Warmumformung
Sheet Steel for Hot Forming

VDA 239-500

1.	Anwendungsbereich und Anlieferungsformen	1.	Scope and Delivery Conditions
2.	Verweisungen	2.	References
3.	Inhaltsstoffe und Wiederverwertbarkeit	3.	Regulated Substances and Recyclability
4.	Abkürzungen, Akronyme und Symbole	4.	Abbreviations, Acronyms and Symbols
5.	Werkstoffarten und Definitionen	5.	Types of Materials and Definitions
6.	Nomenklatur und Bezeichnungsbeispiele	6.	Nomenclature and Examples for Steel Designations
7.	Anforderungen	7.	Requirements
8.	Überarbeitungen	8.	Revisions

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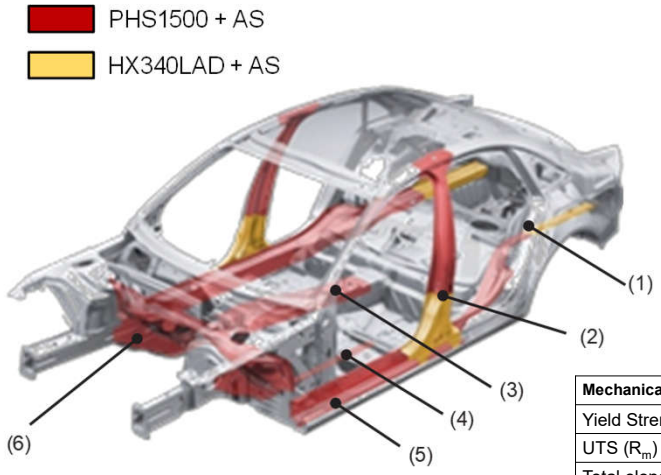
Laser Welded Tailored Blank Applications



2007 – First laser welded tailored blank PHS components in Audi A4.

Mechanical properties after hot stamping	PHS 1500 + AS	HX340LAD + AS
Yield Strength ($R_{p0.2}$) [MPa]	950-1250	430-485
UTS (R_m) [MPa]	1300-1650	490-560
Total elongation (A_{80}) [%]	> 4.5	9-15

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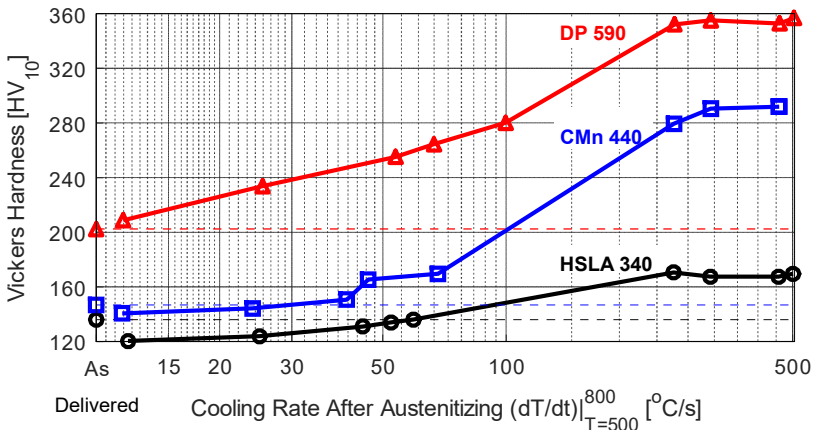
Difference of PQS grades and HSLA



Cold forming steels (HSLA, CMn or DP) are not optimized for PHS process.

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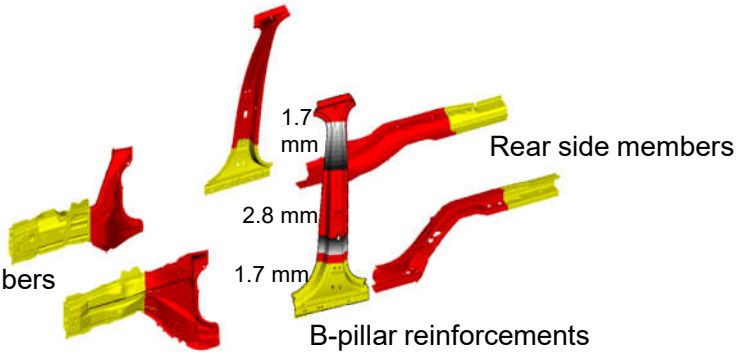
Laser Welded Tailored Blank Applications

Volvo XC90, 2nd Generation
2015-Present



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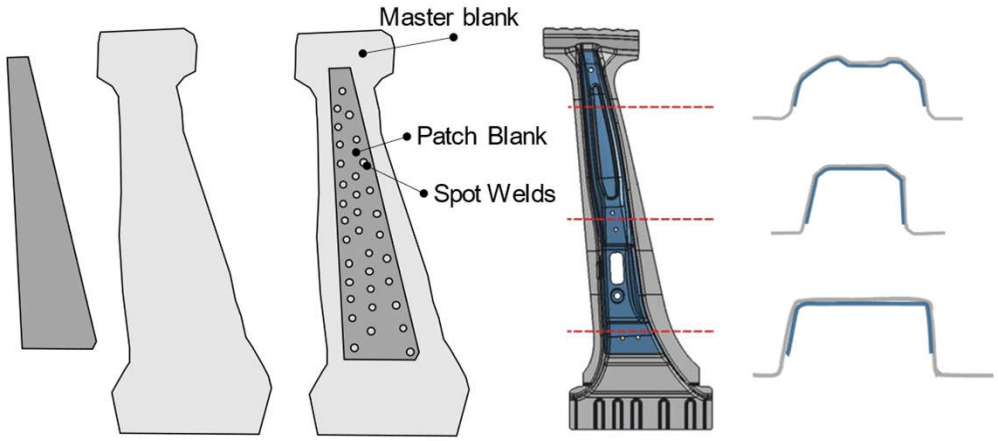
Patchwork Blank Applications



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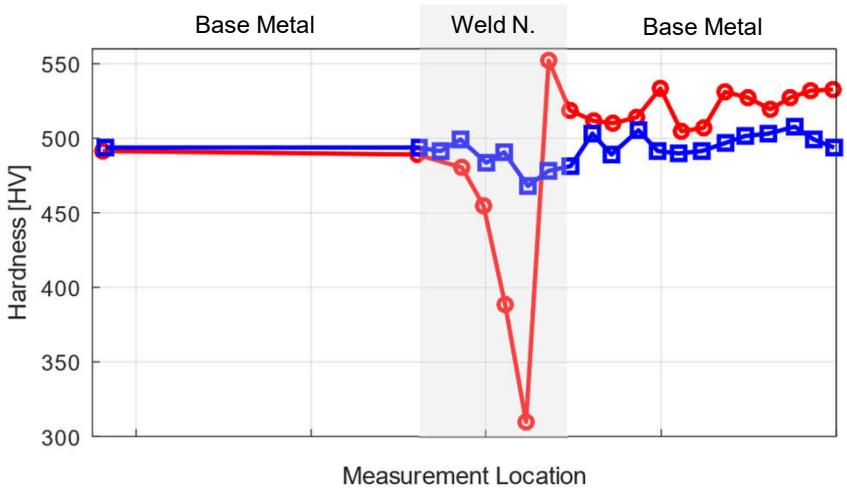
Advantage of Patchwork Blanks



Spot weld applied after PHS

Spot weld applied before PHS

Recreated after E. Billur, Ed., "Hot stamping of ultra high-strength steels: From a Technological and Business Perspective," Springer, 2019, ISBN 978-3-319-98870-2, and K. Uejima, C. Beku and T. Onoe, "The 2015 WRX STI", Presented at EuroCarBody 2014, Bad Nauheim, Germany,

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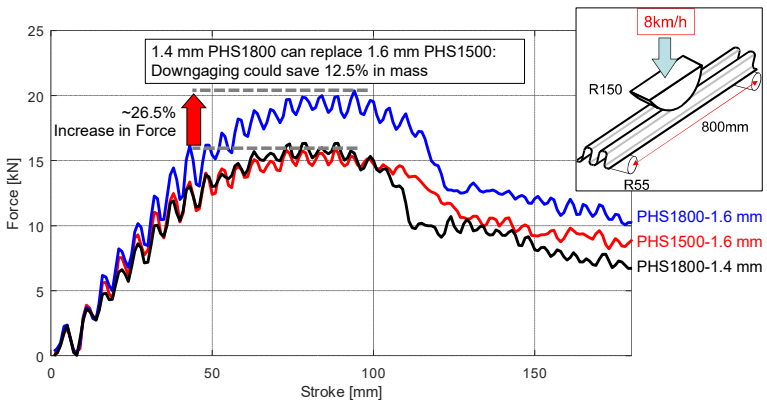
First use of >1500 MPa Steel



2011 – Mazda CX-5 was the first car to have 1800 MPa tensile strength steel.

2019 – VW ID.3 has 1900 MPa sheet components

2019 – Porsche Taycan EV has 1900 MPa closed profile components.

K. Hikita, "Properties of New TS1800 MPa Grade Hot Stamping Steel and Components," Presented at Materials in Car Body Engineering 2012, May 10-11, Bad Nauheim, Germany, 2012.

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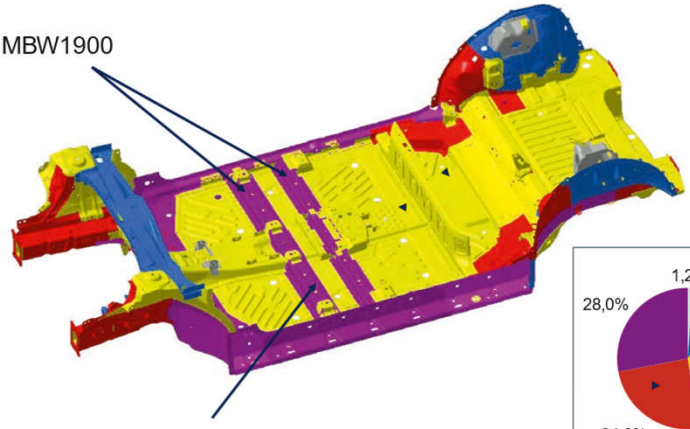
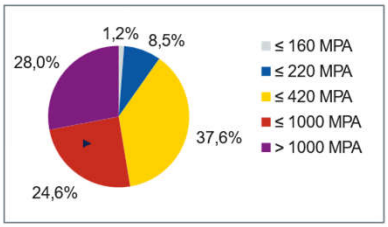
First use of CR1900T-MB

VW ID.3
(2019-Present)

MBW1900



1 concept of seat crossbeam
for all variants of platform



I. Lüken and N. Tenneberg, "Volkswagen ID.3,"
Presented at Aachener Karosserietage, September 17–18, Aachen, 2019.

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First use of AS coated CR1900T-MB

▲ The first Usibor®2000 coil rolling off the production line

https://www.vamachina.com/en/usibor2000-meets-haval-h6/

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Hyundai using 1.8 GPa steel

Hot Stamping Experience and Tech Tour MetalForming Magazine https://esg.hyundai-steel.com/2021/front/contents/contentView.do?menuSn=286&cntntsCode=enep0404 November 29-30, 2023 I Holland, MI

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AS coated CR1900T-MB in Welded Area

Roof Arch Pillar in the Maserati Gracale

Was 1.4 mm CR1500T-MB at 5.1 kg

Converted to 1.3 mm CR1900T-MB at 4.7 kg

Hot Stamping Experience and Tech Tour MetalForming Magazine "Eco-design technical solutions for a sustainable mobility" by Tedesco, De Caro, Ferrea, Barile, presented at IABC 2023 Turin, https://gamcinc.com/cfiles/wp-content/uploads/2023/06/Barile-Presentation-Turin23.pdf. Also see linkedin.com/posts/arcelormittal-europe_iabc-sustainablemobility-automotiveengineering-activity-7071797489372160001-4xX1 November 29-30, 2023 I Holland, MI

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GA Coated CR1900T-MB in Welded Area

Courtesy of Toyotetsu Turkey

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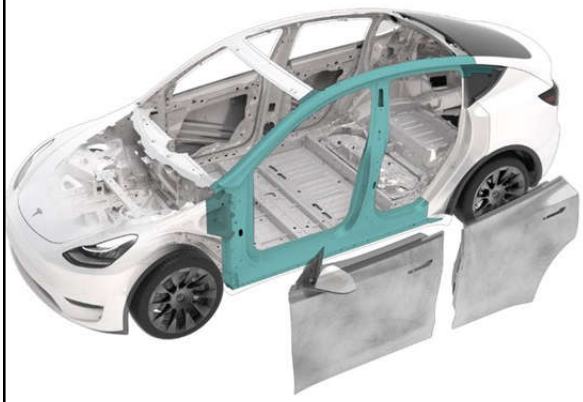
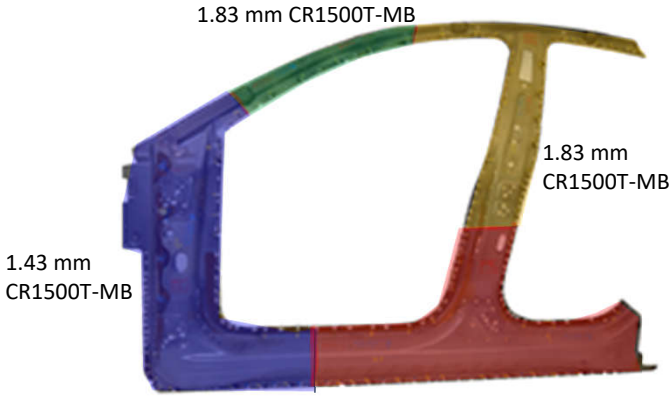
CR1100T-MB (PHS1100) in body applications





References: Tesla Emergency Response Guide, material infographic re-created after A2MAC1

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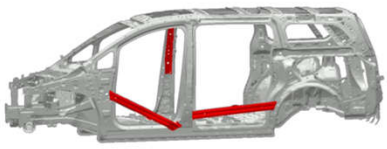
CR1500T-1100T LWB + CR1900T PW



Remember the advantage of Patchwork Blanks?

Han et al 2023, Voyah EuroCarBody 2023

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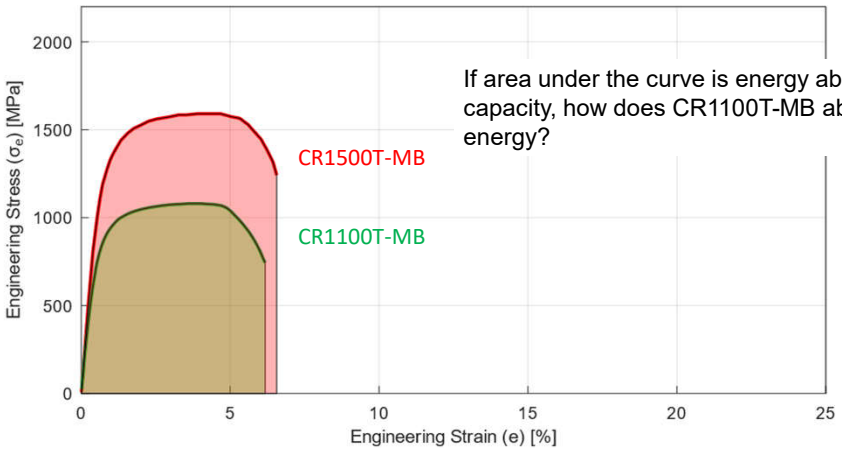
Crash Ductility of CR1100T-MB



If area under the curve is energy absorbing capacity, how does CR1100T-MB absorb more energy?

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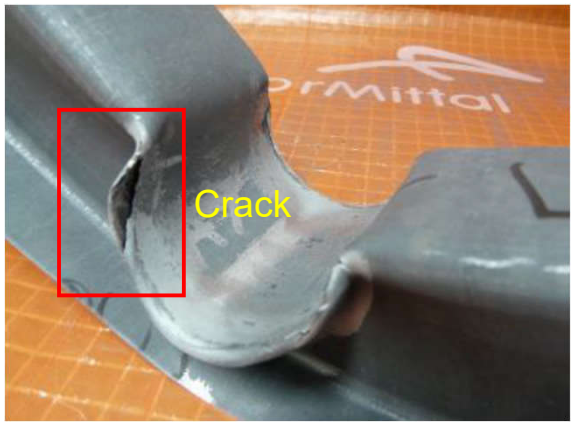
Crash Ductility of CR1100T-MB



CR1500T-MB @ 90 mm stroke of the crash

CR1100T-MB @ 120 mm stroke of the crash
No crack formation

Hot Stamping Experience and Tech Tour MetalForming Magazine

Yang 2018, Valin ArcelorMittal Automotive Steel, Presentation in Changchun.

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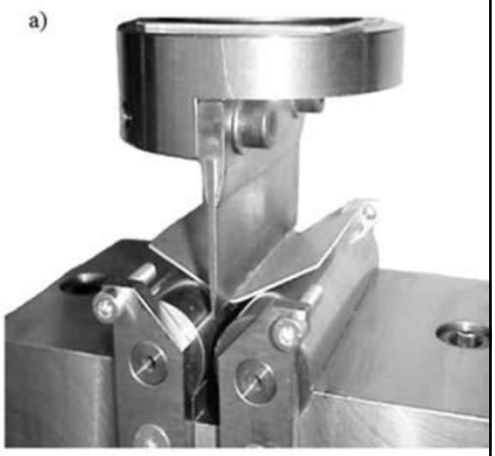
Crash Ductility of CR1100T-MB



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Butcher 2017 and Woelke 2018

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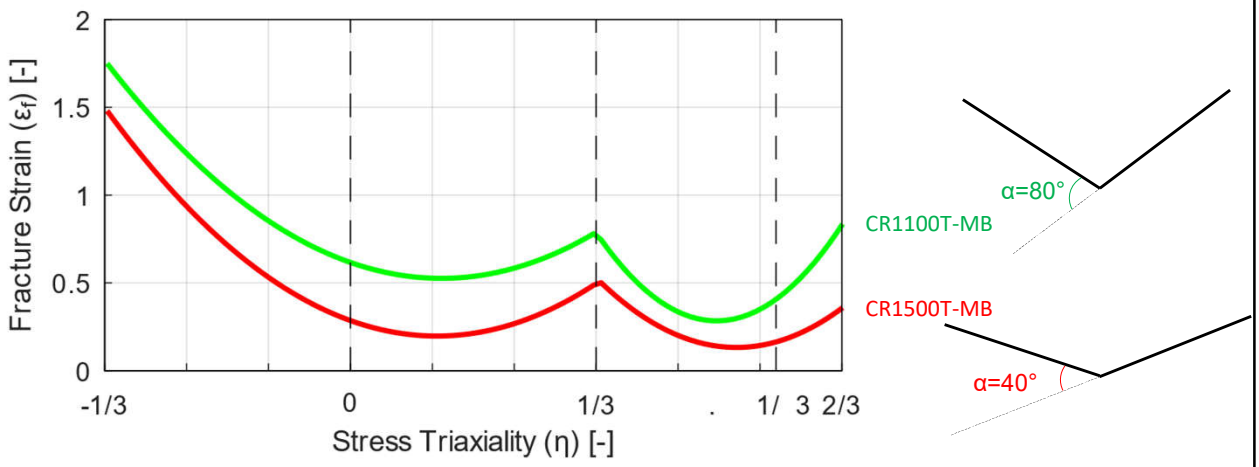
Crash Ductility of CR1100T-MB



41

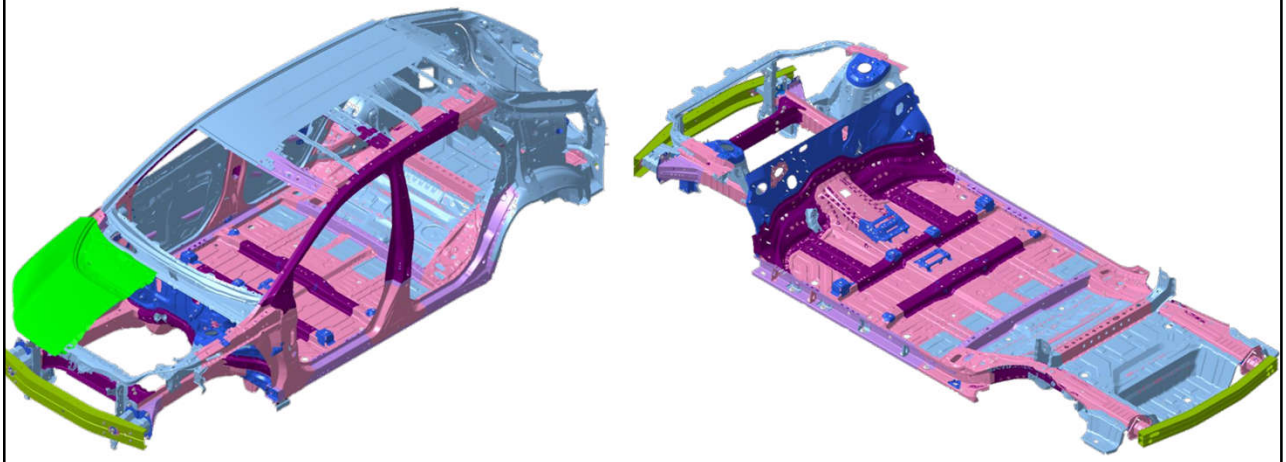
New uses of PHS Grades (Concept, Exposed)

42

New uses of PHS Grades (Concept, Exposed)

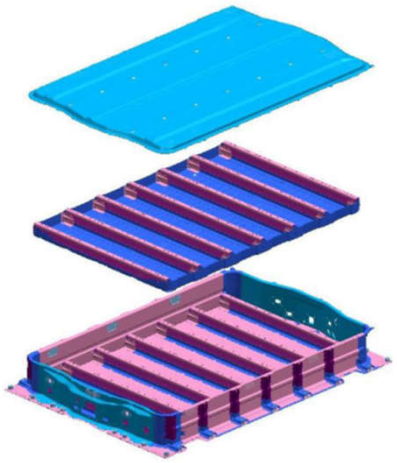
43

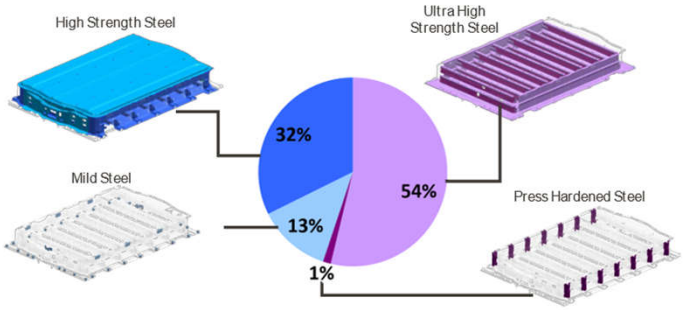
New uses of PHS Grades (EV)



44

New uses of PHS Grades (EV)

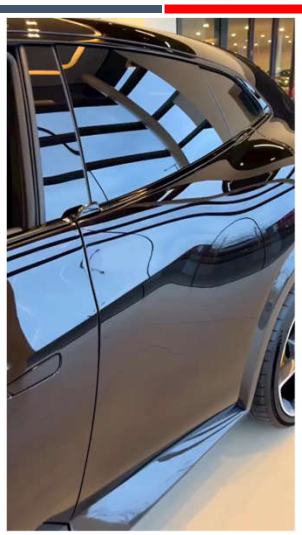




Walker and Veal 2022, EuroCarBody GMC Hummer EV

45

New uses of PHS Grades (PHS Hinge)



Ferrari Media Centre and YouTube

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Outline

- Main drivers for press hardening
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  - Low strength with high ductility grades for crash energy management
  - High strength for intrusion prevention and safety cage integrity
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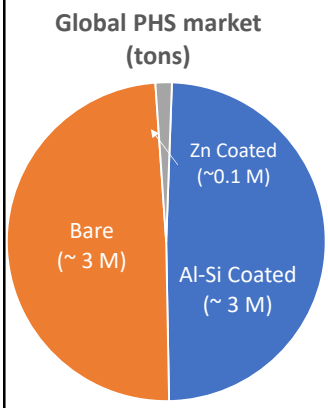
Coating-Free PHS (CFPHS)



Motivation

Bare: Low cost, but decarb + scale in furnace, no oxidation resistance in use

Al-Si coating: solves those issues at a cost ($ and manufacturing challenges)

Stainless steels have lifetime oxidation resistance based on their >12% Cr … comes at a high cost, especially in SS3XX with 8-10% Ni

What if all that was needed was to achieve a short-term high temp stainless-like effect at the furnace temp and have good oxidation resistance in service?

Material	C	Mn	Cr+Si+Mo	Nb+Ti	B	Bal		TS typ	EL typ
22MnB5	0.19-0.25	≤ 1.4	≤ 1.0	≤ 0.12	0.0008-0.005	Fe		1500	7%
CFPHS	0.19-0.25	≤ 1.4	≤ 4.0	≤ 0.12	none	Fe		1680	9%

Based on Tedesco et al, GDIS 2021, 2022, &2023; PMA PHS 2021; Digicon 2022, doi.org/10.3390/met13030489

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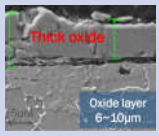
Coating-Free PHS (CFPHS)

	Bare 22MnB5
Surface Condition after Hot Forming	
Oxide / Coating Morphology	
Advantages and Drawbacks	Low cost Risk of decarburization within furnace; Poor oxidation resistance; Requires die cleaning; Requires post-forming shot blasting

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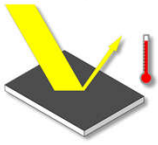
Thermoboost®

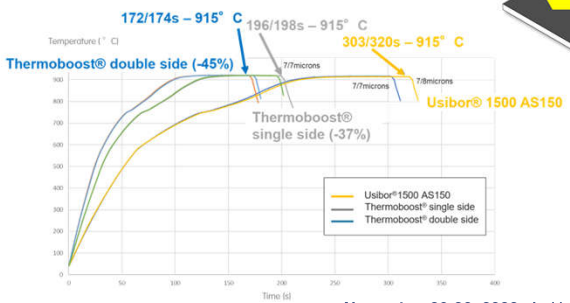
Black primer layer over AlSi layer → ↑ surface emissivity = absorb heat

- heat quicker,
- pick-up less hydrogen in the hot stamping furnace,
- enlarges process window for more robust multi-thickness blanks



Compared to Usibor® 1500 AS

- Dwell time reduction of 45%
- Diffusible hydrogen reduced to 0.16 ppm from 0.23 ppm



Ramisetti, 2021 PMA Hot Stamping Experience

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Heat Resistant Paint Instead of Al-Si

Pre-ceramic polymer with Si –C backbone, aluminum powder, and solvent

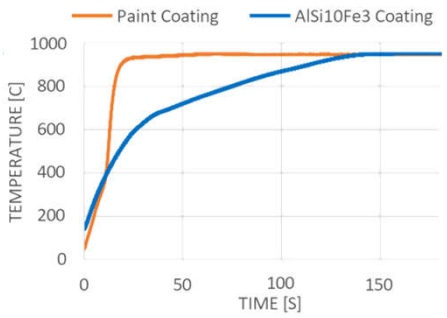
- polymer-to-ceramic conversion during heating

Faster curing than required AS furnace time

No surface scale formation during furnace heating

Good coating adhesion during plastic deformation

Acceptable tensile, welding, E-coating, & corrosion



Mechanical Props	YS [MPa]	TS [MPa]	Total Elong [%]	Hardness [HV]
Specification	**950 min**	**1300 min**	**5% min**	**400 min**
2mins@930C	1010	1410	5.9	450
5mins@930C	980	1400	5.5	445

Chiriac et al "New Coating Development for Press Hardening Steels," International Symposium on New Developments in AHSS Steels, 2023, doi.org/10.33313/298/012; imis.aist.org/store/detail.aspx?id=PR-298-012

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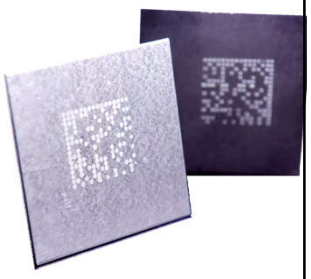
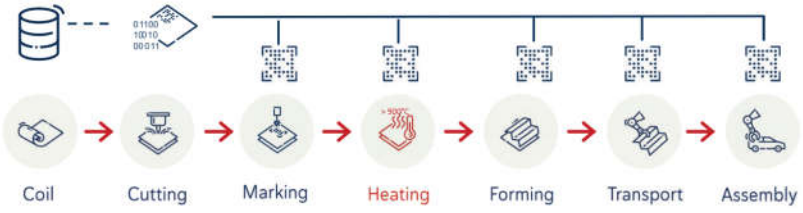
CeraCode® from Senodis for Part Marking

Heat-resistant ceramic ink, stable up to 1200 °C

- component-specific identification
- component traceability
- piece-precise containment





Senodis, Digicon 2022 ; senodis.io/en/solutions/ceracode-individual-part-marking-in-press-hardening/

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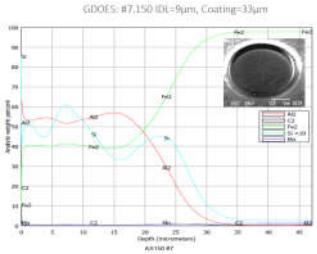
Rapid Coating Thickness & IDL Measurements

- Variation adversely affects paintability, microcracking, surface ductility, surface hardness, and weldability.
- Traditional measurement techniques are slow (sample, mount, polish etch) and look at a very small area.
- Using GDOES takes analysis time from 4+ hours to ~15 minutes and looks at a much larger area.
- Allows for faster processing response (furnace adjustments) if thickness is trending too high



Total coating thickness:
where Al crosses C

IDL thickness:
see patent for details

Chiriac, 2021 PMA Hot Stamping Experience; https://patents.google.com/patent/US20190301983A1/en

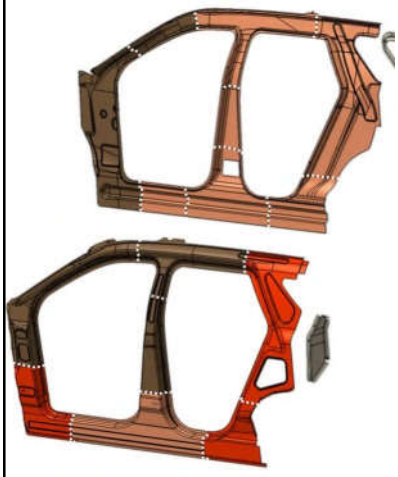
Hot Stamped Q&P Treatment on 3rd Gen Steels

- 3rd Gen Steels with 980 MPa TS: High press forces, springback
- Solve challenges with Q&P processing
  - 750°C for 5 min; quench to 230 °C, reheat to 400°C for 2 min; quench
- Same hardness as DP980 and 3rd Gen 980 (~300 $HV_{0.2}$)
- 5% more retained austenite than 3rd Gen 980 (20.5% vs 15.4%)
- 5x Punch force reduction vs 3rd Gen 980 (100 mm dia hemi punch)

Material/processing Condition	Hardness (HV_0.2)	V-bend angle (degrees)	YS (MPa)	UTS (MPa)	T. El (%)	Toughness (MJ/m^3)
DP-980-AR	308±6	86±1	629±8	997±7	18.3±0.4	173
3rd Gen 980	304±7	96±1	677±4	1033±8	27±0.5	255
Q&P-FH-0	297±10	118±2	708±6	939±5	35±0.5	310

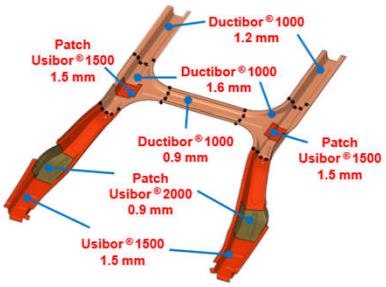
T. Skszek, Pacific Northwest National Laboratory, presented at 2023 A/SP Technology Day and iopscience.iop.org/article/10.1088/1757-899X/1284/1/012028/meta

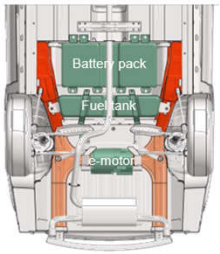
Extreme Size & Multi-Part-Integration (PHS)



Just like in giga-casting, if part consolidation can be done in intrusion resistance areas, with very large stampings, PHS may be cost efficient!

2-door rings* and rear H-frame are proposed.





Hot Stamping Experience and Tech Tour MetalForming Magazine

Ref: Paegle and Wilsius 2021.

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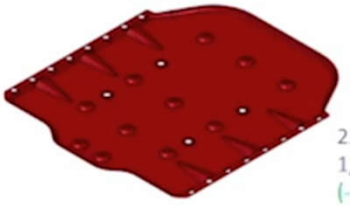
Extreme Size & Multi-Part-Integration (PHS)

EN AA 5182
3 mm – 16,8 kg
(not OK in bollard)
6 mm – 33,6 kg
(to pass bollard)



22MnB5 AS60/60
1,3 mm – 21,2 kg
(- 37% weight)

Hot Stamping Experience and Tech Tour MetalForming Magazine

Ref: Belanger 2023

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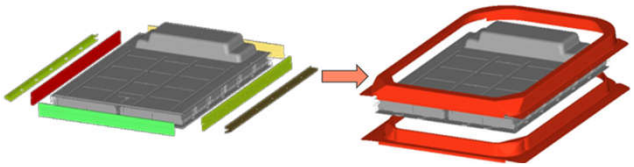
Extreme Size & Multi-Part-Integration (PHS)

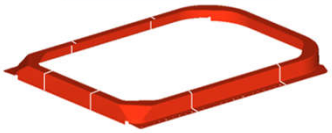
Billur Engineering Quality Solutions

Part Consolidation = Cost Savings!



Around a battery frame, instead of 10 pieces, 2 LWBs may suffice.

Floor Ring Upper



Floor Ring Lower

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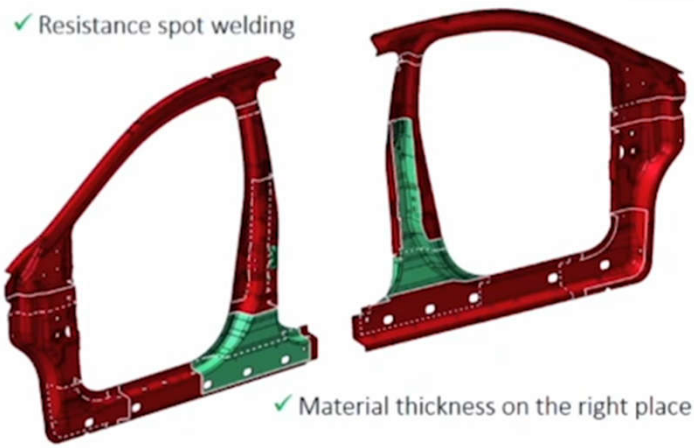
Extreme Size & Multi-Part-Integration (PHS)

Billur Engineering Quality Solutions

✓ Resistance spot welding



✓ Material thickness on the right place

Instead of laser welded blanks:
Overlap patchwork blank

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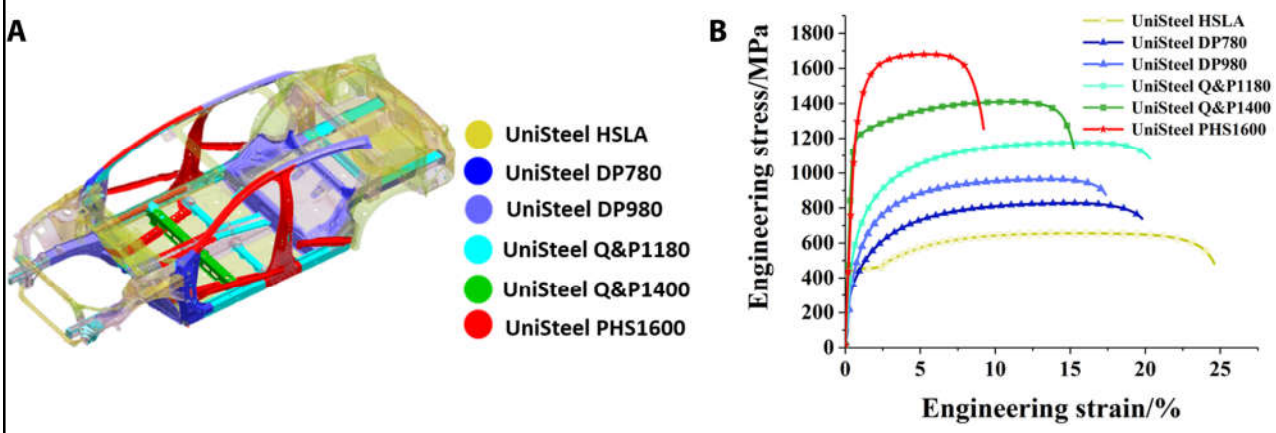
Making car body with single alloy: UniSteel



Hot Stamping Experience and Tech Tour MetalForming Magazine

Lu, Qi, et al. "Revolutionizing car body manufacturing using a unified steel metallurgy concept." *Science Advances* 7.49 (2021): eabk0176.

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- Main drivers for press hardening
- Common PHS/PQS Grades
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  - High strength for intrusion prevention and safety cage integrity
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  - Recent Enhancements
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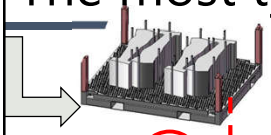
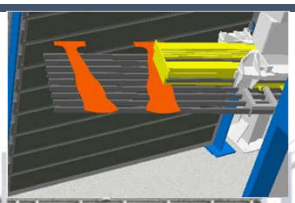
The most typical process route

Billur Engineering Quality Solutions



Blanking

1



2

3

4

Destacker and marking

Cartesian or Robotic

Furnace

Roller hearth or chamber

Press

Mostly Hydraulic 1000-1200T

Commonly 3.000 x 2.200 mm table

End of line

Cartesian or robotic

Laser cut

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MetalForming Magazine

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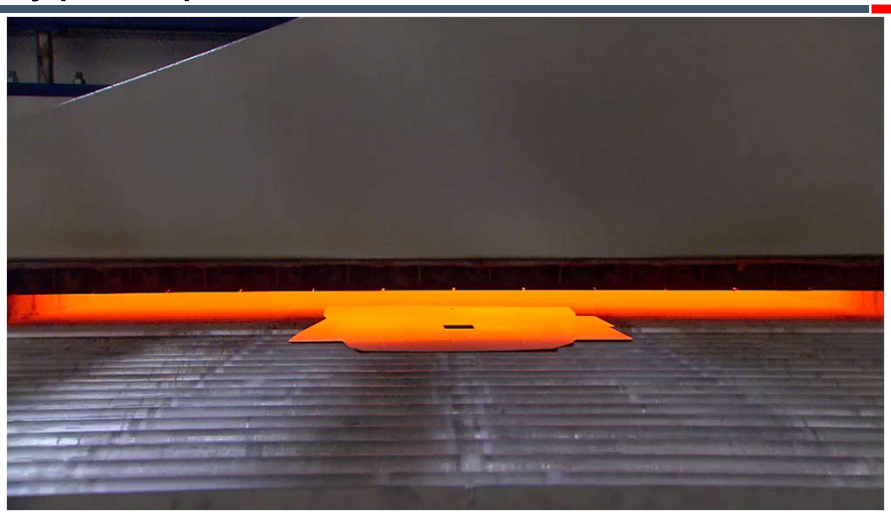
The most typical process route

Billur Engineering Quality Solutions



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Ref: Volkswagen Media Services

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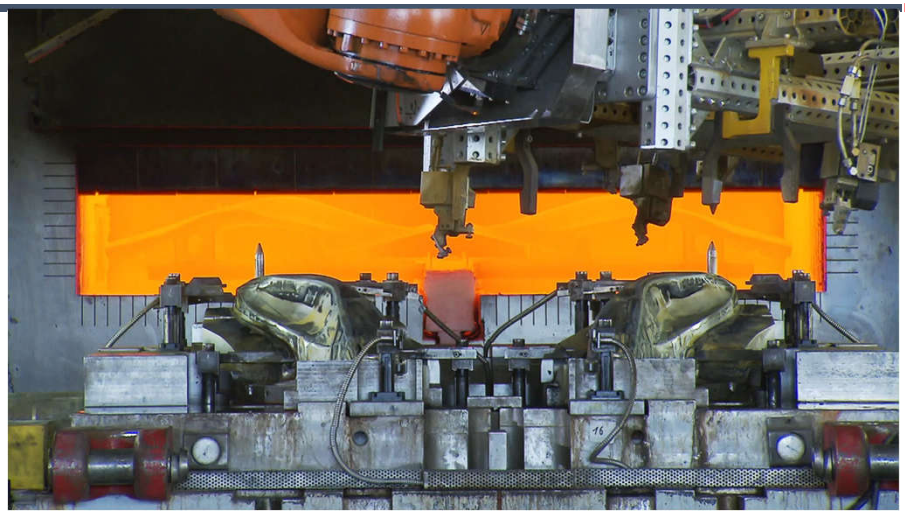
Indirect process route



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Coating Strategy Influences Direct vs Indirect

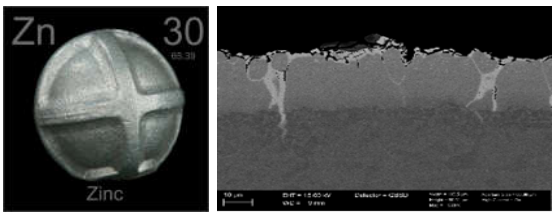
Press hardened steel blanks are heated to > 900°C

Hot dipped aluminized steel
Al/Si-layer: 90% Al – 10% Si
Melting point of Al–Si coating: ~600°C

AlSi fractures when cold formed

Hot dipped galvanized / galvannealed (GI/GA) steel
(Zn-layer)
Pure zinc melts at 419°C … and vaporizes at 906°C

Molten zinc → Liquid Metal Embrittlement



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Directform: pre-cooled forming of 20MnB8 GA

Ref: voestalpine YouTube

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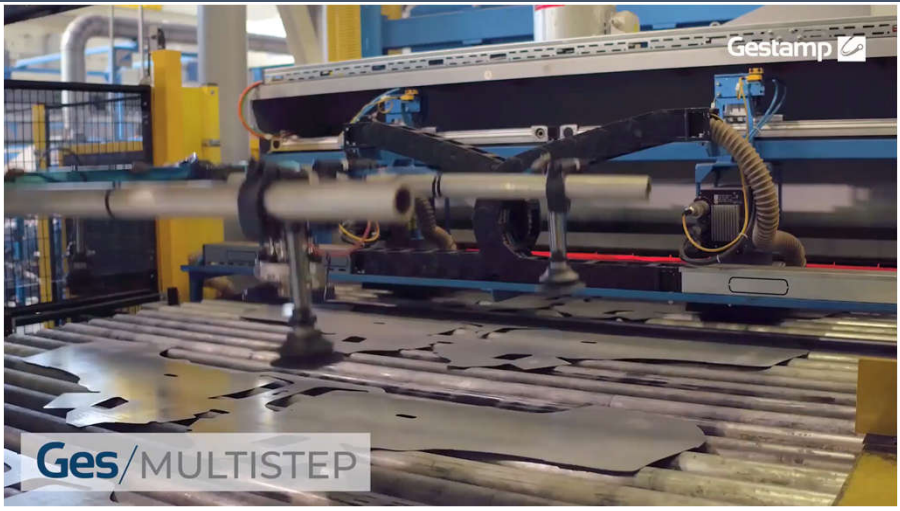
MultiStep: Servo Press Forming of 22MnBSi9-5 GA



Ref: Gestamp Youtube

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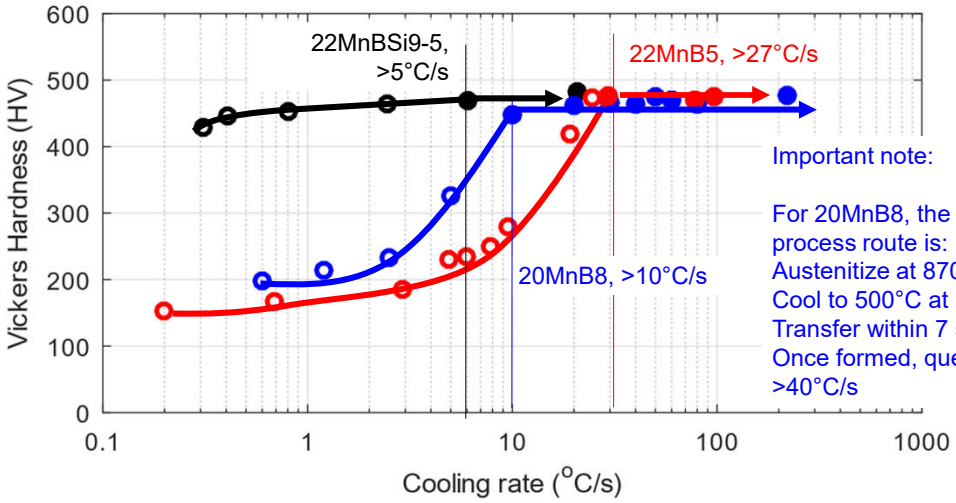
New grades for new process routes



Important note:

For 20MnB8, the suggested process route is:
Austenitize at 870°C
Cool to 500°C at >20°C/s
Transfer within 7 seconds
Once formed, quench at >40°C/s

Recreated after Herbelin 2014, Kurz 2016, Hamamoto 2017.

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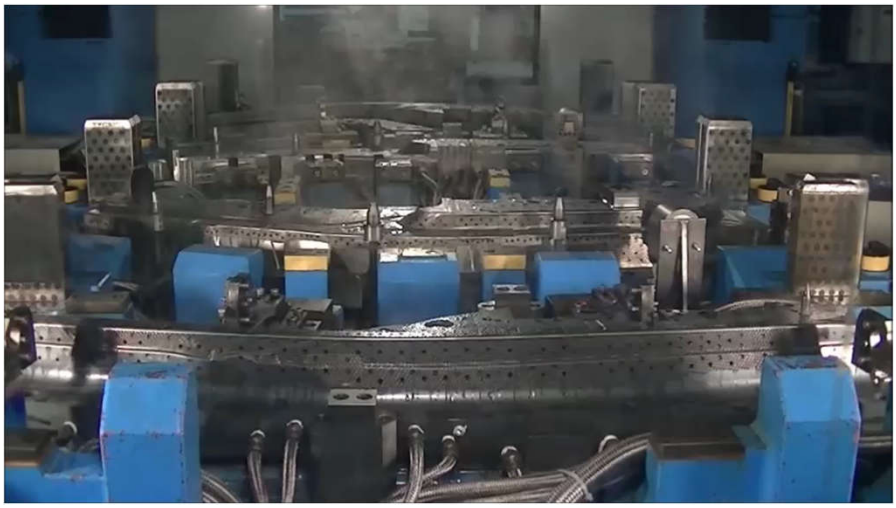
Direct water cooling (special grade)



Courtesy of UniPres

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Vacuum hot forming


Laser blanking


Vacuum heating


Hot forming


Product


Electro-Galvanizing


Laser cutting

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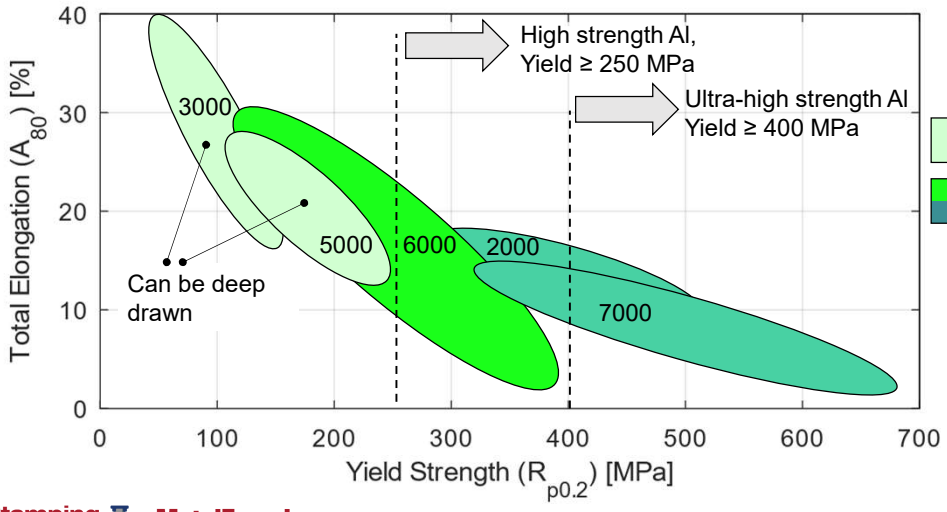
Aluminum grades



Own work, re-created after Afseth 2015 and Klos 2018.

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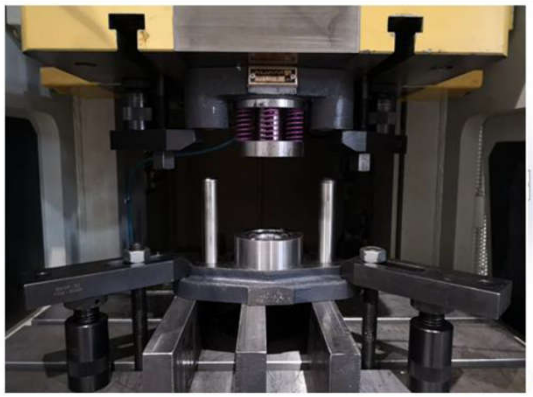
7075-T6 formability



A simple cup draw die-set, 50 mm diameter punch

Round blank
7075-T6
2 mm thick
70 mm diameter

80 Metric Ton
Servo Press

Ref: Lotfi et al. 2021 (including E. Billur).

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7075-T6 formability @ Elevated Temperatures

Furnace capable of heating over 500°C

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Ref: Lotfi et al. 2021 (including E. Billur).

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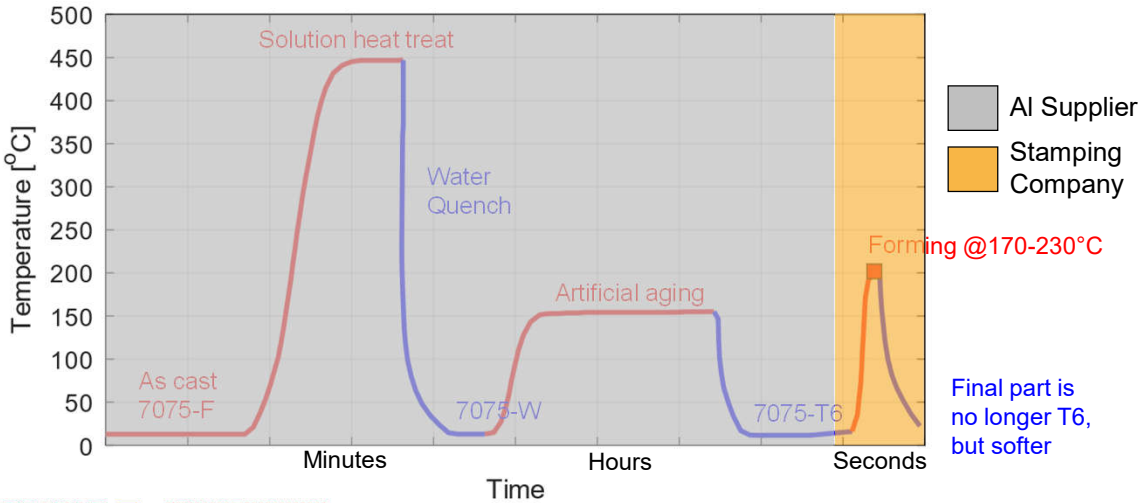
Strategy #1: Warm Form



Own work, re-created after Grohmann 2015

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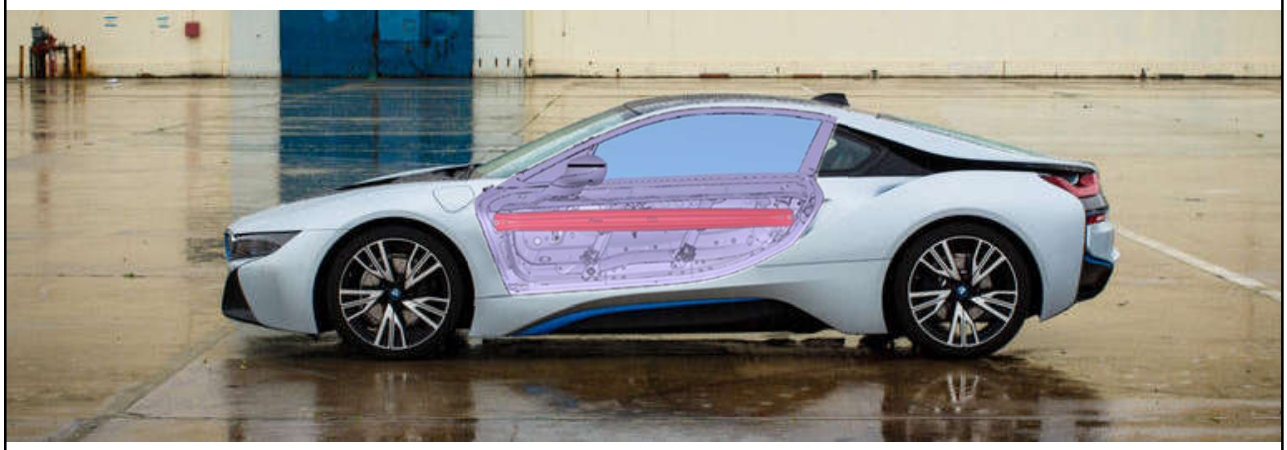
7075 Door Beam (production)



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Reinstettel 2014, Insight Edition Aluminum - Collage made by Billur Metal Form

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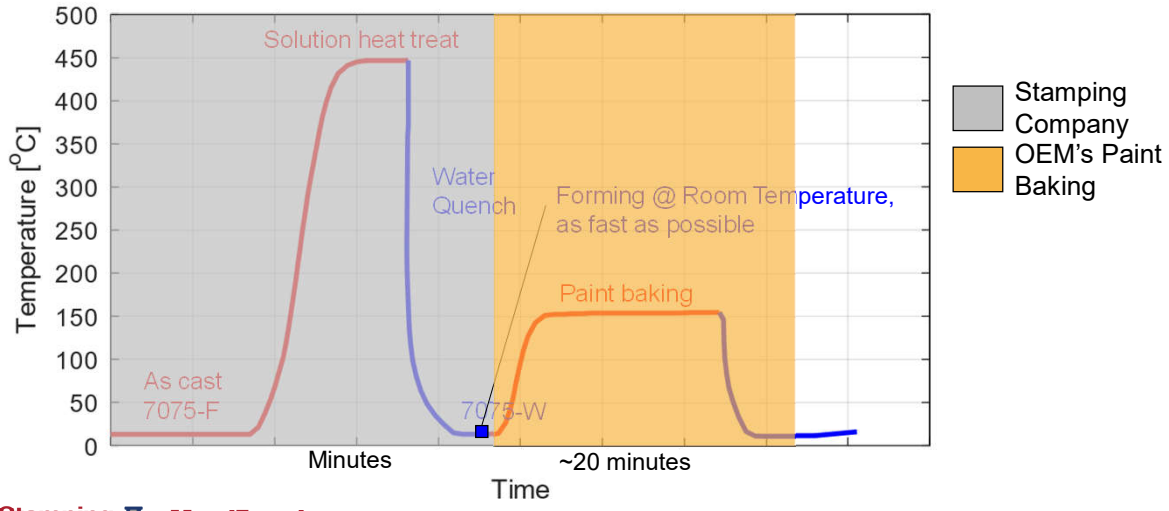
Strategy #2: W-Temper Form



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Own work, re-created after Grohmann 2015

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Strategy #2: W-Temper Form

Cold Form 5182-O

Cold Form 7075

W Temper Form 7022

W Temper Form 7075

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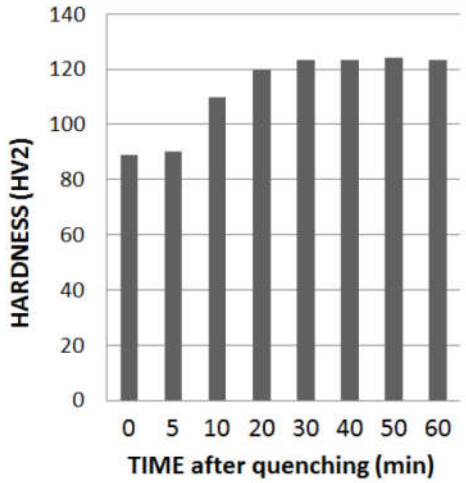
W-Temper Form Advantages / Disadvantages

In W-temper, forming is done in cold condition:

1) Less tool maintenance and less complicated process

2) F-Temper material can be bought, reducing the incoming material cost. More Al suppliers may be able to supply the material.

3) However, forming has to be done as soon as possible after the W-tempering. Otherwise, the material may start aging.



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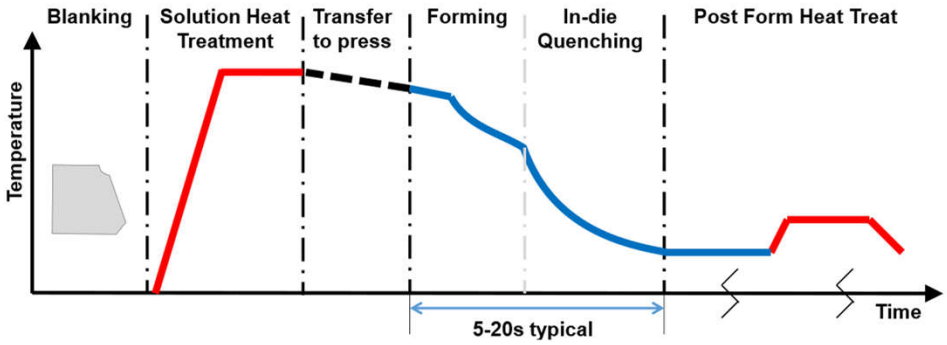
Strategy #3: Hot Form & Quench



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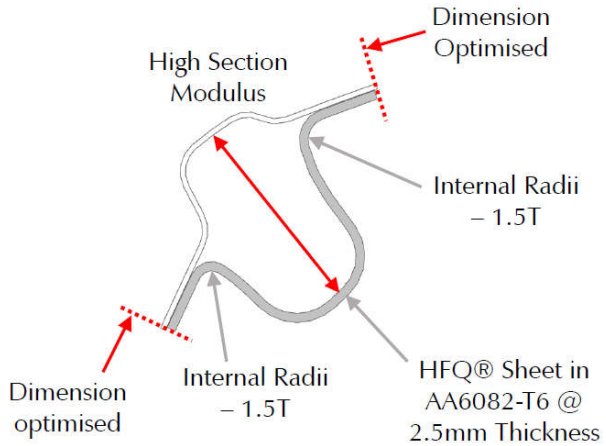
Hot Forming of 6082-T6



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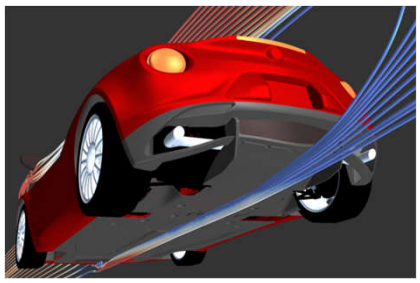
Hot Forming of 6016

Alfa Romeo 4C
2013-2020



Incoming blank:
1.5 mm 6016

Formed at 450°C in a PHS line!

Ref: Consalvo 2013

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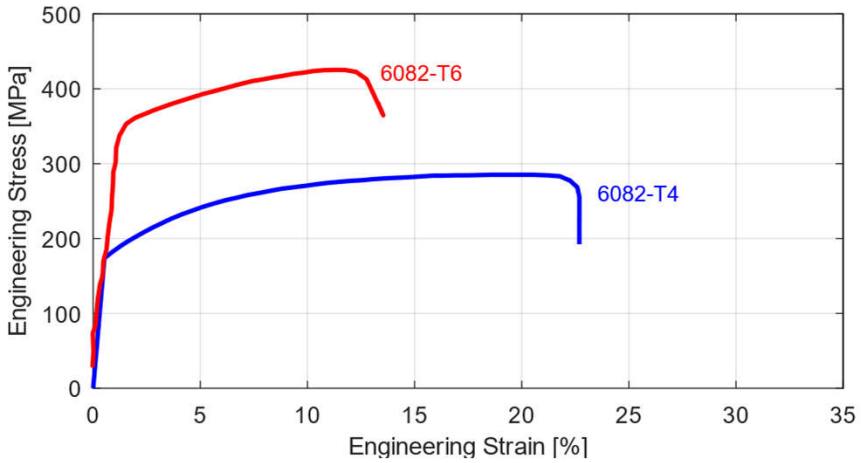
6082 – Hot Formed



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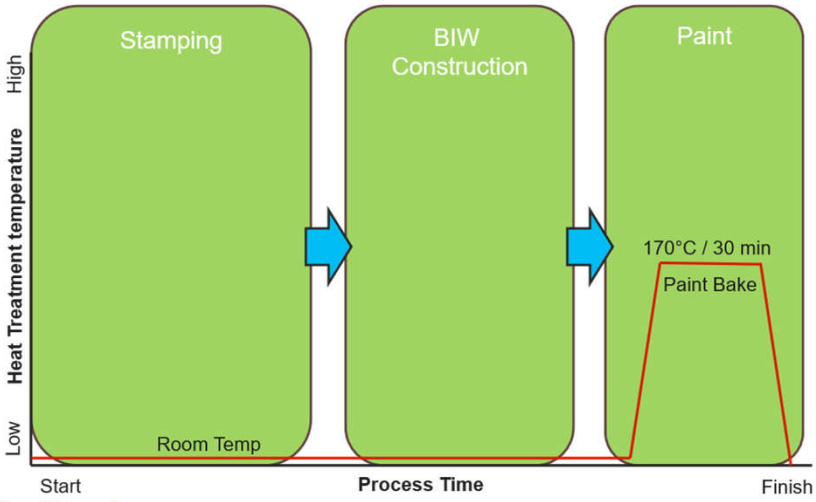
Conventional 6000 aluminum workflow



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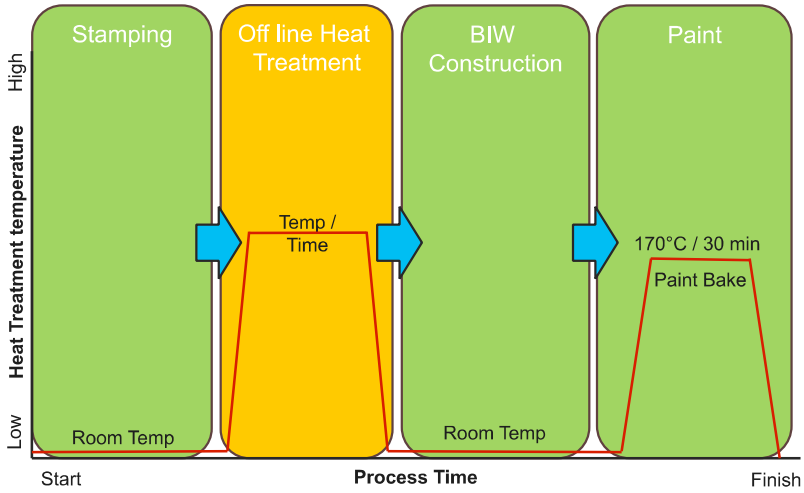
High strength 6000 aluminum workflow



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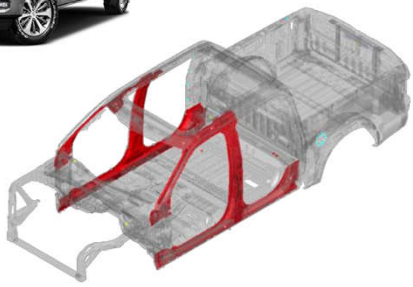
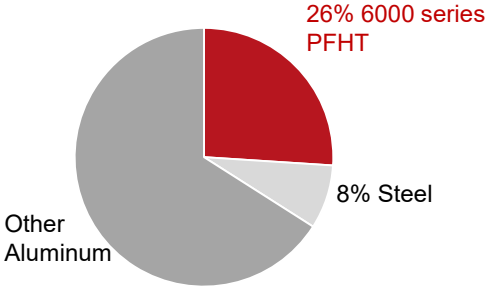
Highest volume AIV

Ford F-150 (13th Gen.)
2015 - Present





Re-created after: Keller and Wagner 2015, EuroCarBody

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Superplastic Forming

Superform YouTube Channel

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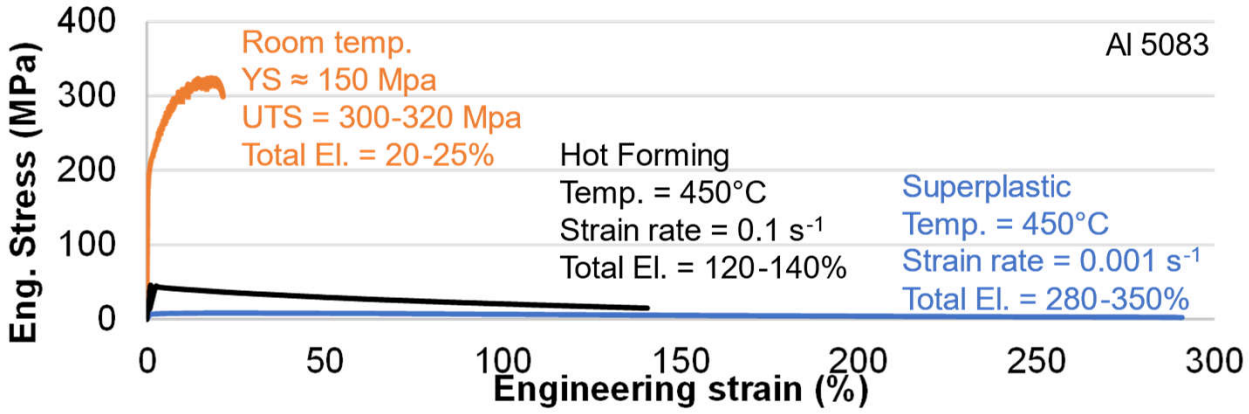
Superplastic Forming



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SPF Usage in Automotive

88

Comparison of methods

	Cold	Warm	W-Temper	Hot	SPF
Formability	O	+	++	+++	++++++++
Process cost	O	$$	$$$	$$$	$$$$$
Cycle time	2.5-10 sec	10-20 sec	2.5-10 sec	5-20 sec.	Over minutes
Applicability	O	+	?	+	+

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Outline

- Main drivers for press hardening
- Common PHS/PQS Grades
  - Low strength with high ductility grades for crash energy management
  - High strength for intrusion prevention and safety cage integrity
  - Techniques for tailored strength, stiffness, or energy absorption within a single part
- Emerging Grades and Technologies
- Typical Process Route
  - Recent Enhancements
- Warm and hot stamping of aluminum alloys
- **Competition to press hardening**

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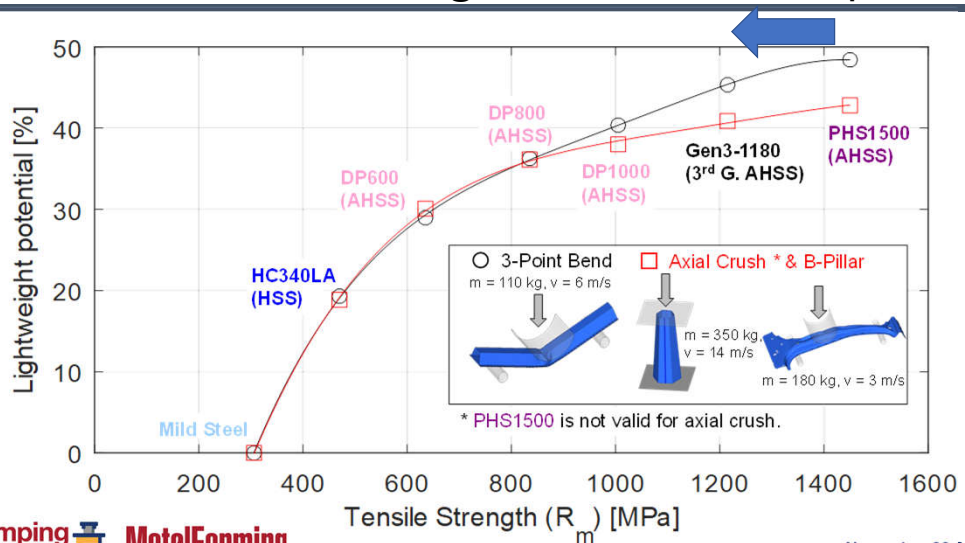
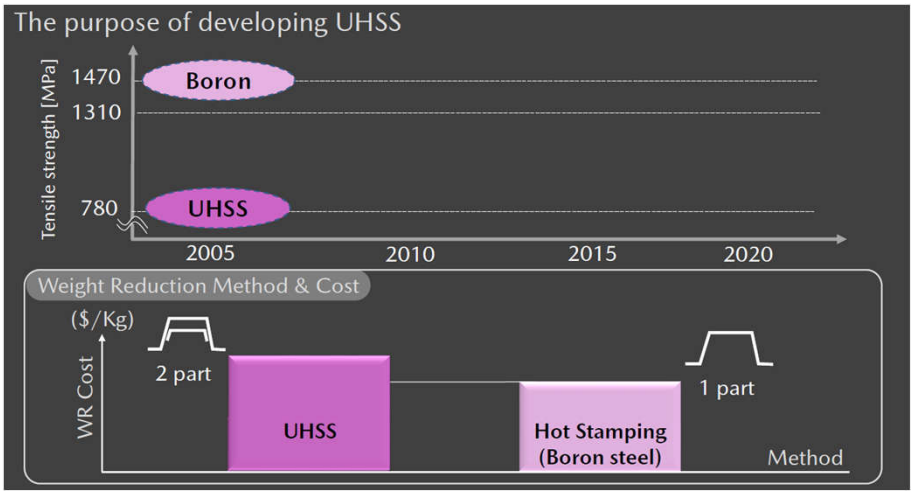
PHS seems to be increasing, but there is competition



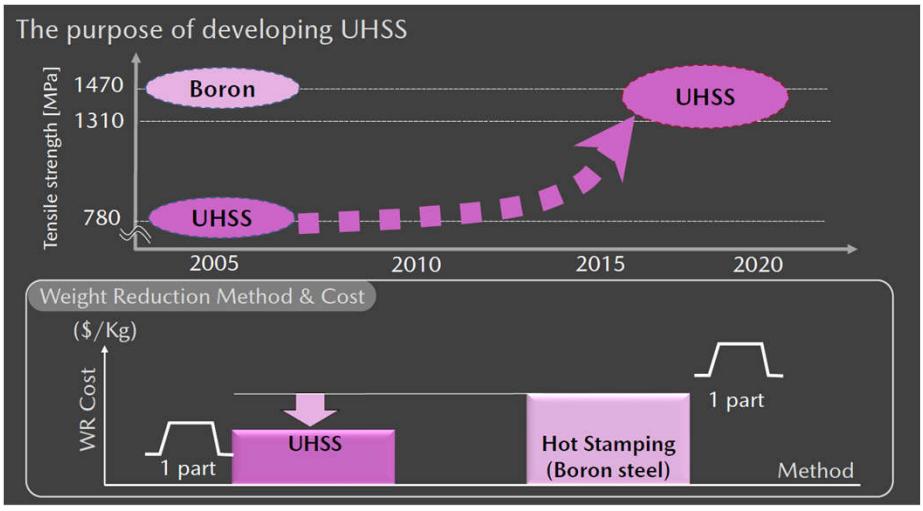
Ref: Billur et al 2021 (data from Özkan 2020)

DP Steels were not a big threat to PHS



Ref: Kobashi and Kawano 2020

But Gen 3 may be game changing



Ref: Kobashi and Kawano 2020

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Comparison of PHS and Gen3

PHS1500

Blanking — Heating — Hot forming and die quenching — Trimming

Easier to cut soft steel

Easy to control springback

Gen3 Steel

Blanking — Transfer press forming — Trimming

No need of heating

Short cycle time

Hard trimming possible

Ref: Billur 2021, data from Kondo 2021

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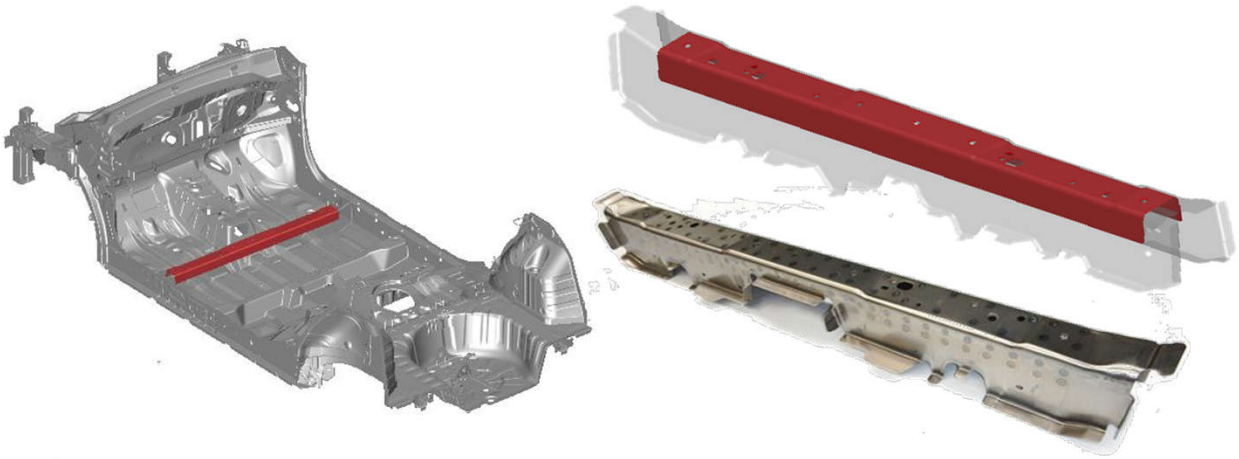
1500 MPa can be now cold stamped



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T. Kondo, "The highest strength (1.5GPa) steel application for cold stamping parts" presented at Materials in Car Body Engineering 2021, June 9, 2021.

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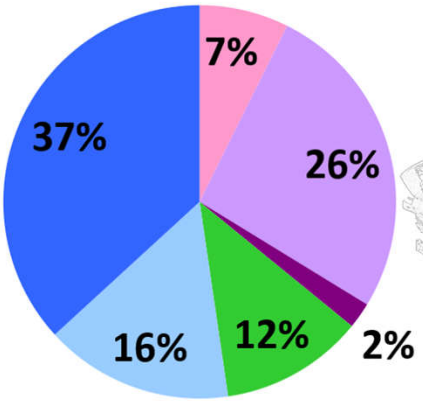
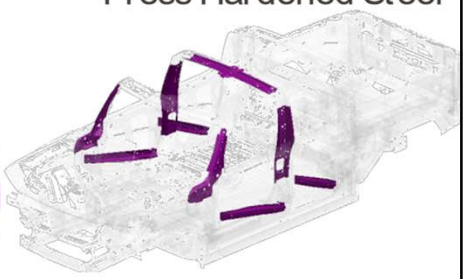
Martensitic steels can be used in simple geometries

Ultra High Strength Steel

2% PHS
18.5% CP
14.3% MART



Press Hardened Steel



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Ref: Walker and Veal 2022

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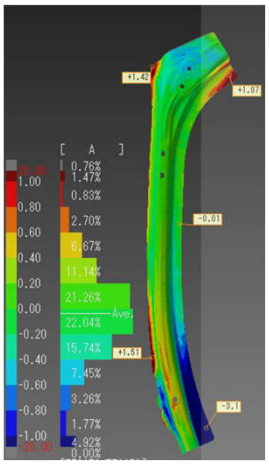
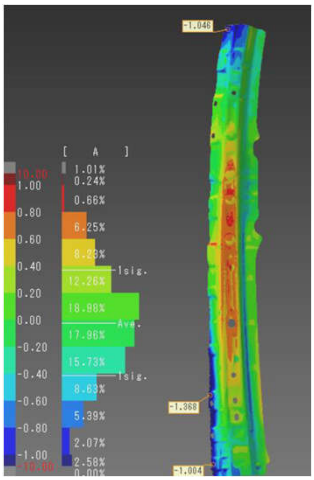
3rd Gen can be used even in A-Pillars!



1.2 mm
1470 MPa
Cold Stamp
A-Pillar

1.4 mm
1470 MPa
Cold Stamp
Roof Rail
(Cantrail)



Ref: Kawasaki et al 2022

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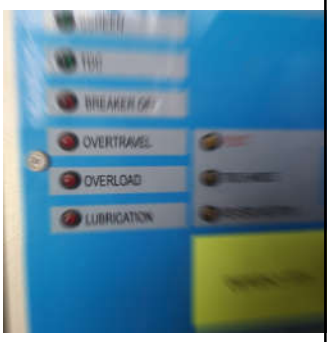
There are 4 big challenges in cold forming:

Hard to control springback

Low formability



Tonnage/Energy

Tool Life?

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Summary

- Increasing use of press hardening steels and/or hot formed aluminum are needed to reduce body structure weight while simultaneously helping to:
  - Achieve a one-platform strategy to produce ICE, BEV, and pHEV powertrains
  - Reduce the body weight increases associated with electrification
  - Meet the ever-increasing crash/crush/safety regulations
- PHS grade options have UTS ranging from 1000 MPa to 2000 MPa after full hardening
  - PQS pairs with PHS grades in the hot stamping process, creating areas of lower strength but higher ductility, cut edge stretchability and energy absorption.
- Regions within a single part can have tailored strength, stiffness, or energy absorption
- Warm and hot stamping of 6XXX and 7XXX-series aluminum alloys can produce parts needing high strength like pillars and door beams. Superplastically hot formed 5XXX produces Class-A parts needing high ductility like fenders and decklids
- Cold formed 3rd Gen Steels and higher-forming martensite may take over some PHS applications