2015-IDE Conference

Hot Hydroforging for Lightweighting

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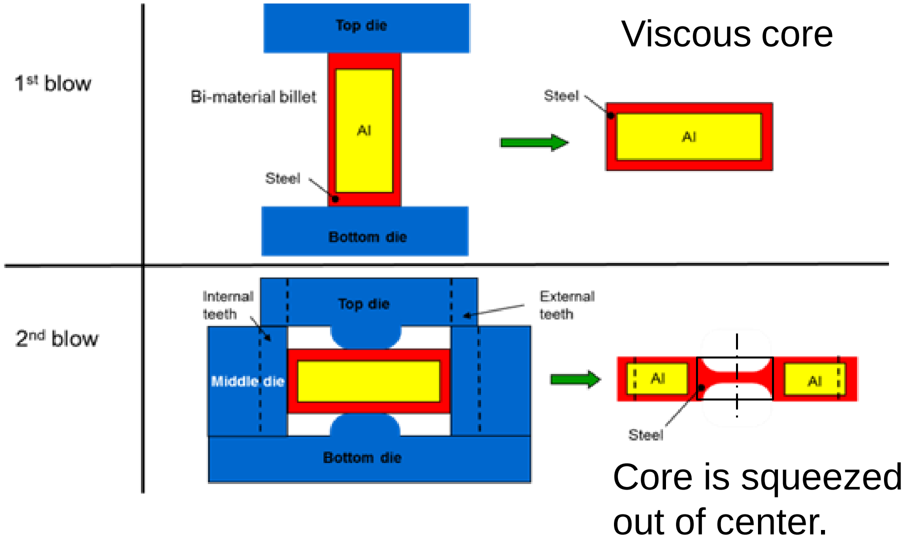
What is Hot hydroforging?

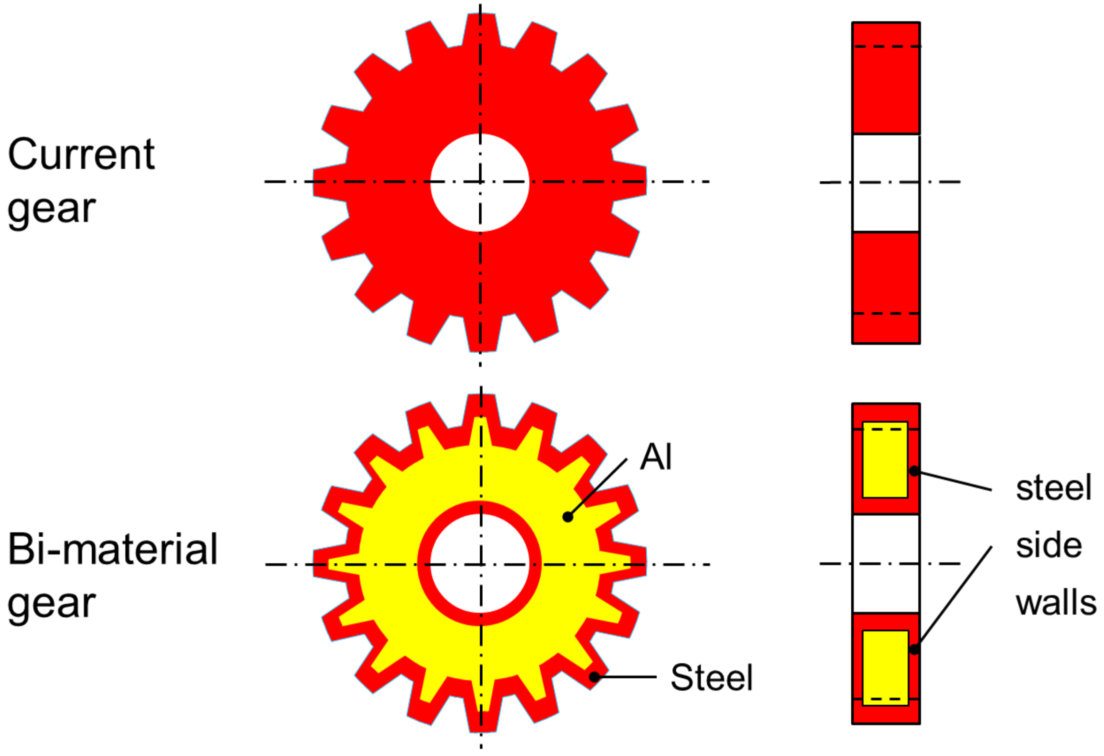
Definition: Hot forging of lightweight products from a hybrid billet of a metal shell and a low melting core.

Concept: Hot hydroforging is done at temperatures where the core material is in viscous state and builds up uniform pressure thereby enabling a uniform deformation of the metal shell.



Goal: Lightweight net shape forging with complex topologies

Hybrid lightweight gear

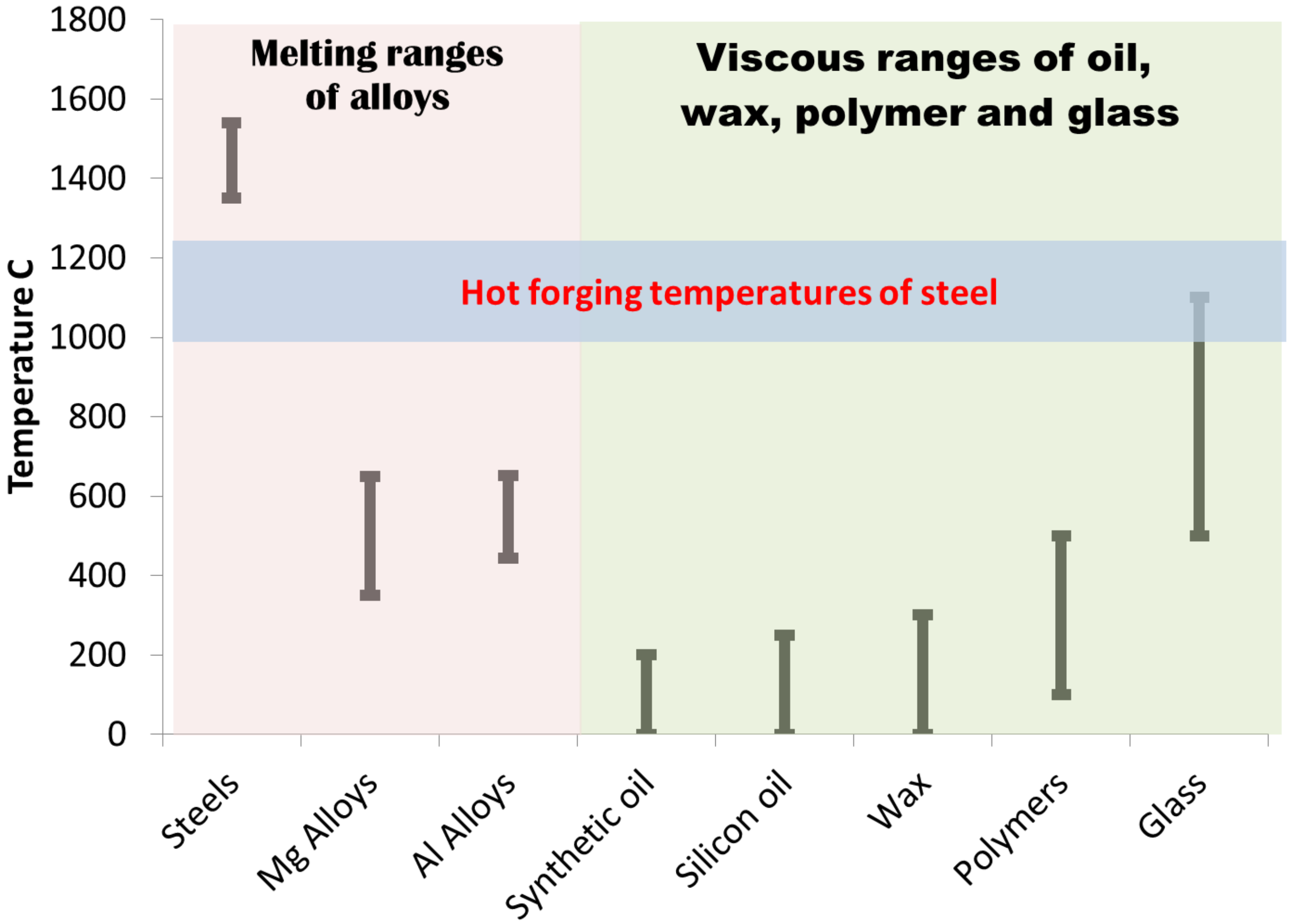


The outer structure is steel, the inner structure is a low melting lightweight material.

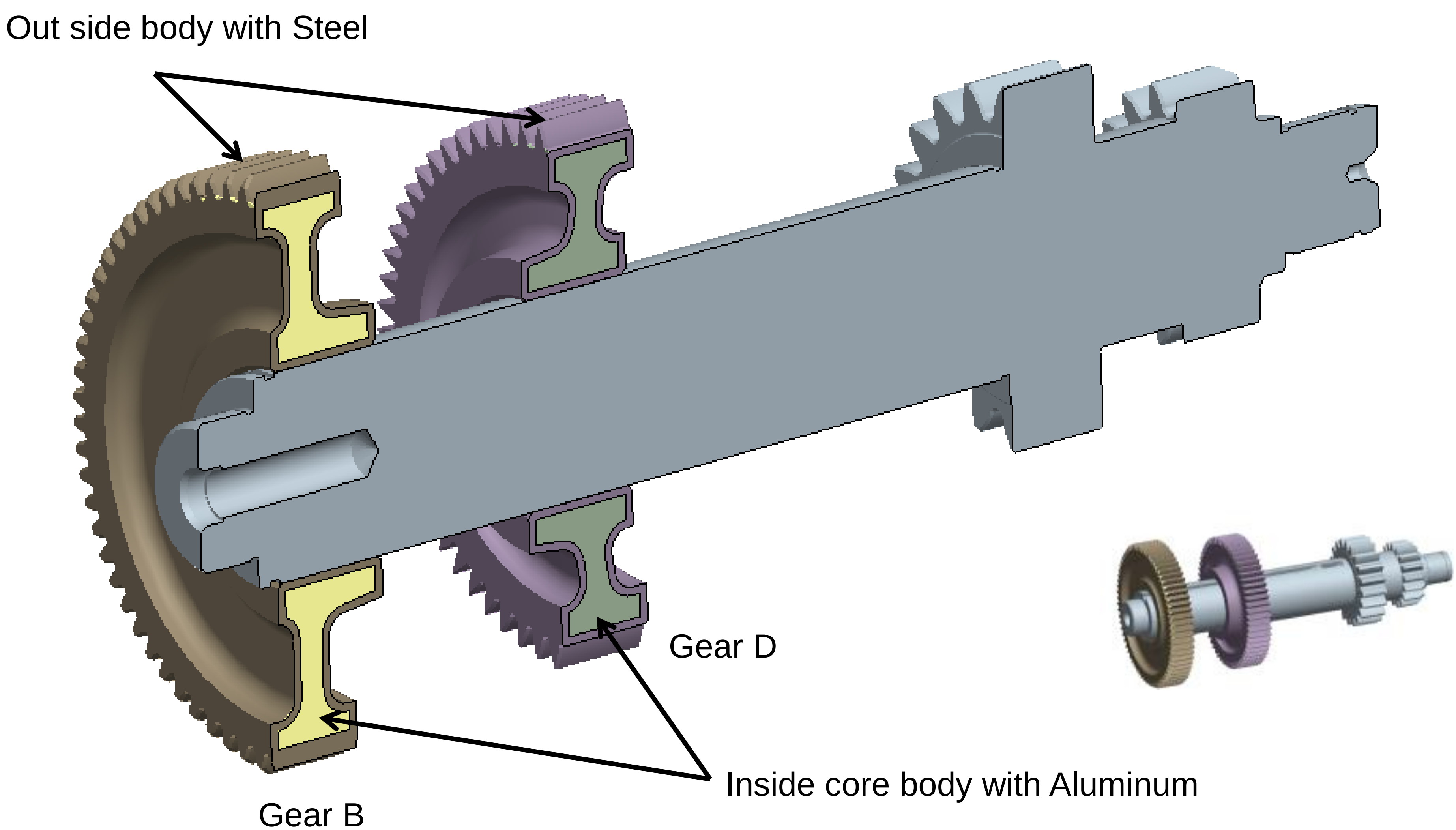
Objectives

- Forging light weight hybrid gears with net teeth and near net center.
- The hybrid gear has all steel outer structure.
- Investment forging is enabled (molten core can be emptied).
- Press loads are reduced and larger gears can be forged.
- 30% to 50% weight reduction per gear is targeted.
- Up to 10% weight reduction per transmission is expected.
- 60% to 70% reduction in machining scrap rate due to near net teeth.
- Gear teeth can be induction hardened with significant energy savings.

Steels and low melting point materials



Structural FEA Modeling of Hybrid Gears 2.5 mm thick steel cover



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Subassembly Deformation and Stress, All Steel Gear and Hybrid Forged Gear

Deformation		Hybrid-Bi-Metal forging			All Steel		
		Gear B	Gear D	Countershaft	Gear B	Gear D	Countershaft
	Total (mm)	0.48	0.425	0.297	0.46	0.421	0.294
	Angular (^{0})	0.31	0.31	0.31	0.3	0.3	0.3
	Radial (mm)	-0.063	-0.127	-0.127	-0.06	-0.122	-0.123
	Axial (mm)	0.081	-0.0442	0.032	0.077	-0.043	0.031

Stress (MPa)		Hybrid-Bi-Metal forging		All Steel	
		Gear B	Gear D	Gear B	Gear D
	Von-Mises	825	876	761	745
	Max principal	730	728.96	696	673.6
	Min principal	-934	-977.87	-859	-831

No stress or deflection is increased more than 8% for the bimetal gear compared to the all-steel gear

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Hybrid billet design for hot hydroforging

Steel tube

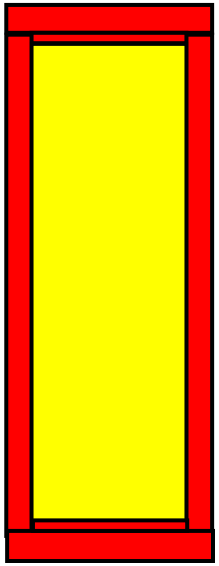
seamless, and w/ seam

0.25” and 0.5” wall

Al bar

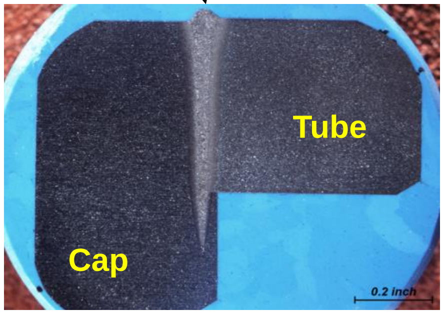
Interference fit

0.003”, and 0.005”



Weld bead

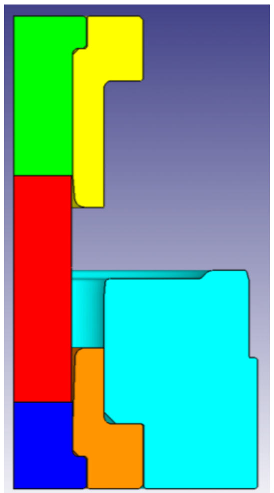
Electron beam welding



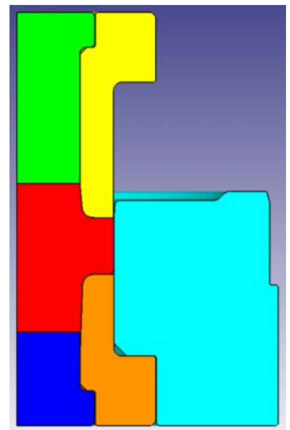
Factors	Levels	
Wall thickness	0.25” (6.25 mm)	0.5” (12.5 mm)
Steel tube type	seamless	with seam
Interference fit	0.003”(0.075mm)	0.005” (0.125 mm)
Forging technique	Hot (solid state)	Hot hydroforging

Die design and simulations

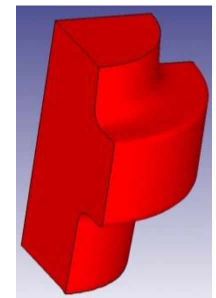
Before forging

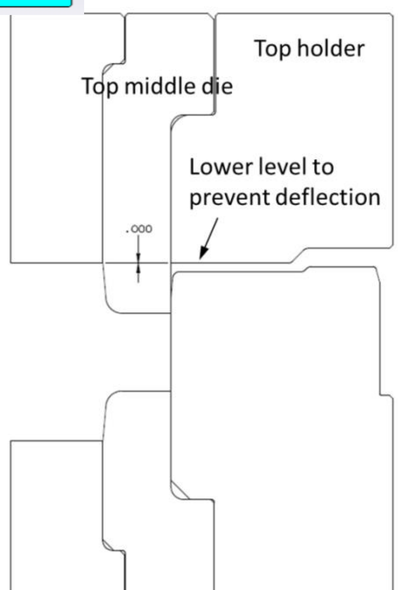


After forging



Forged part

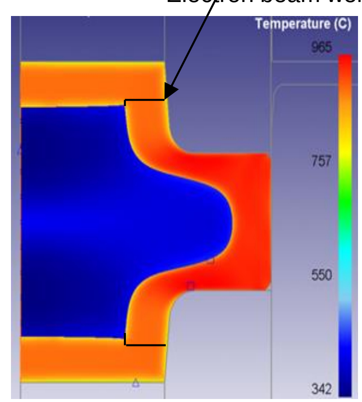




Closed and split die

Weld bead

Electron beam welding



The pockets in the top and the bottom dies keep the weld zone of end caps under compression during busting forging.

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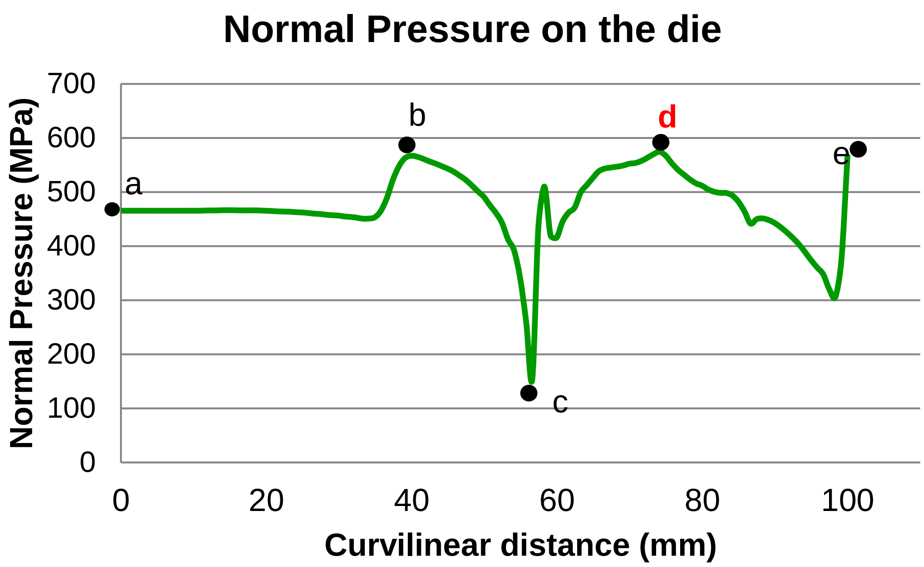
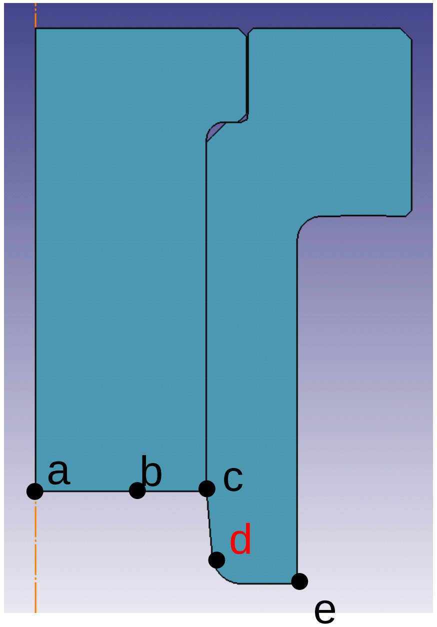
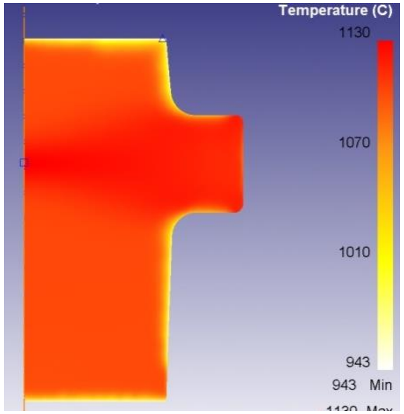
Die stress analysis





Forging temperature: 1100C



Ram displacement (mm/406mm)	Forge load (ton)	Fill radius, **d** (mm)	Stress at the die fillet, **d** (MPa)
405.90	973	1.50	2120
405.87	758	2.30	1750
405.68	552	4.25	1320

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Interpower High Frequency Induction Power (10 kHz, 500 kW)

Interpower Induction controller being built up

New Interpower coil for high frequency

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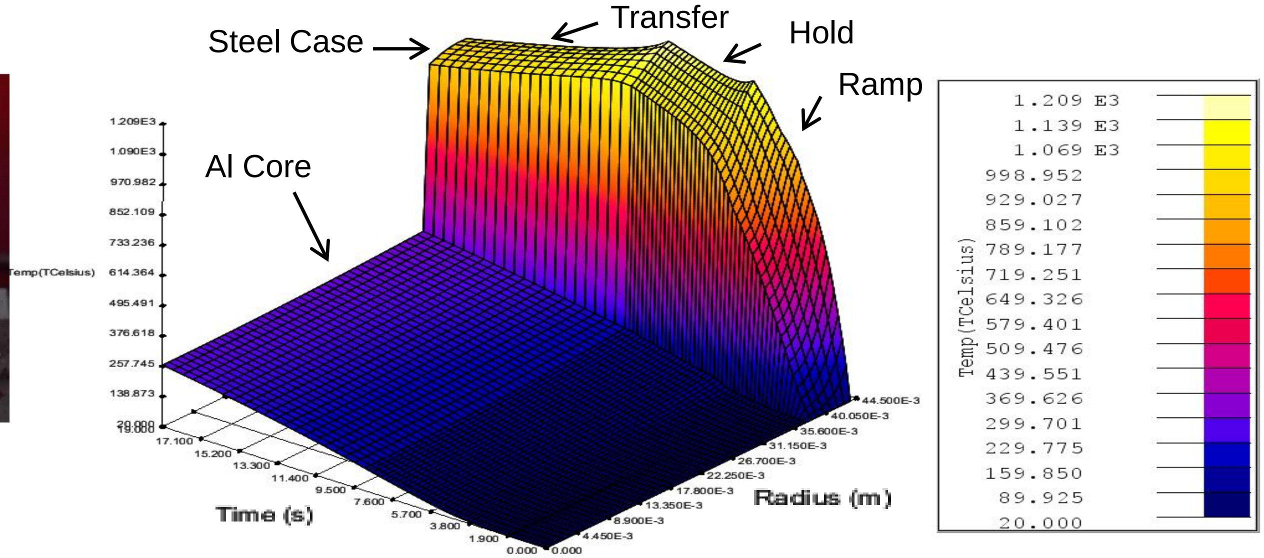
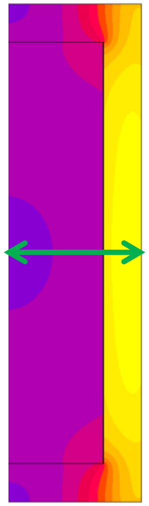
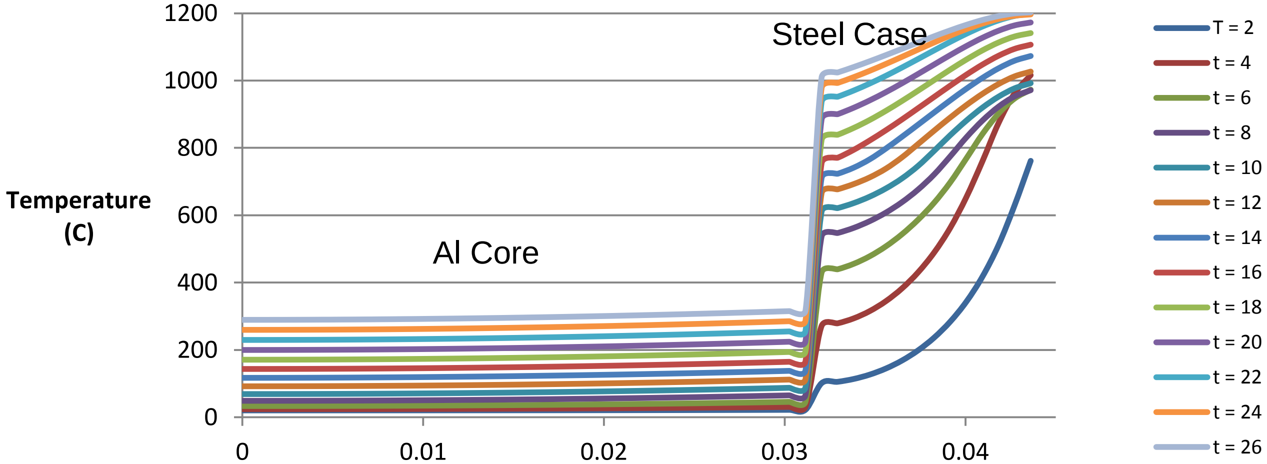
Induction heating simulations for solid state hot forging
Temperature vs. time in the radial direction







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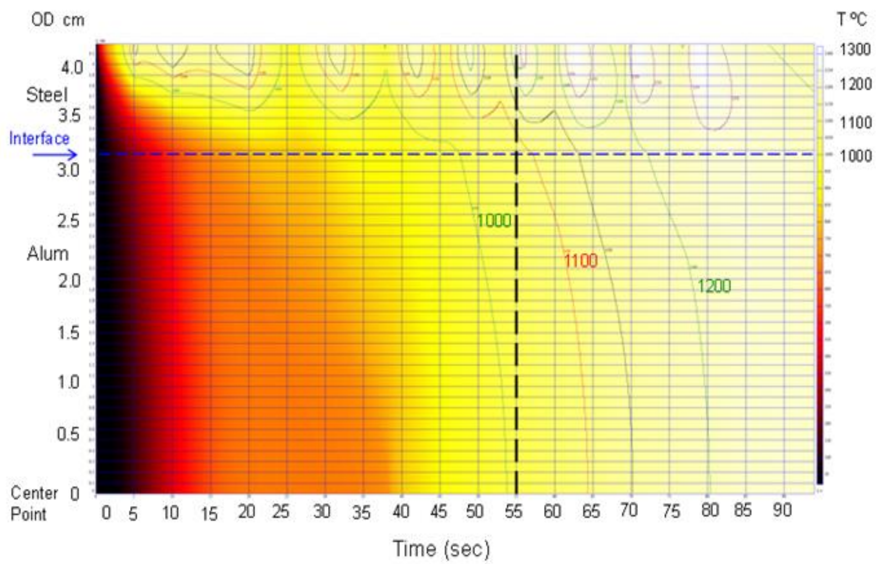
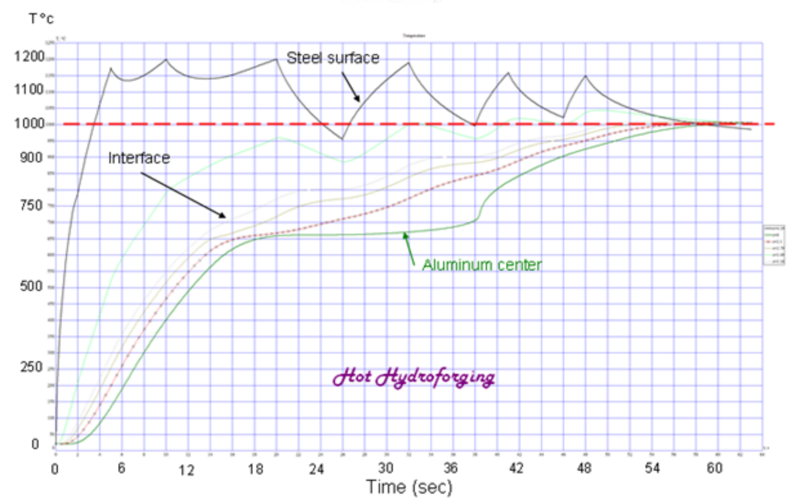
Both steel and aluminum are in solid state

Due to differential heating rate steel shell pulled away from the core

Billet induction heating simulations for hot hydroforging, on-off control strategy



Iso-temperature lines showing the temperature distribution in the radial direction from the center axis to the outer diameter of the billet at mid height of the billet as function of the heating time. The heating simulation shows the effect of on/off control strategy



Heating simulation shows that aluminum core reaches 1000C in 6 on/off cycles in 60 seconds

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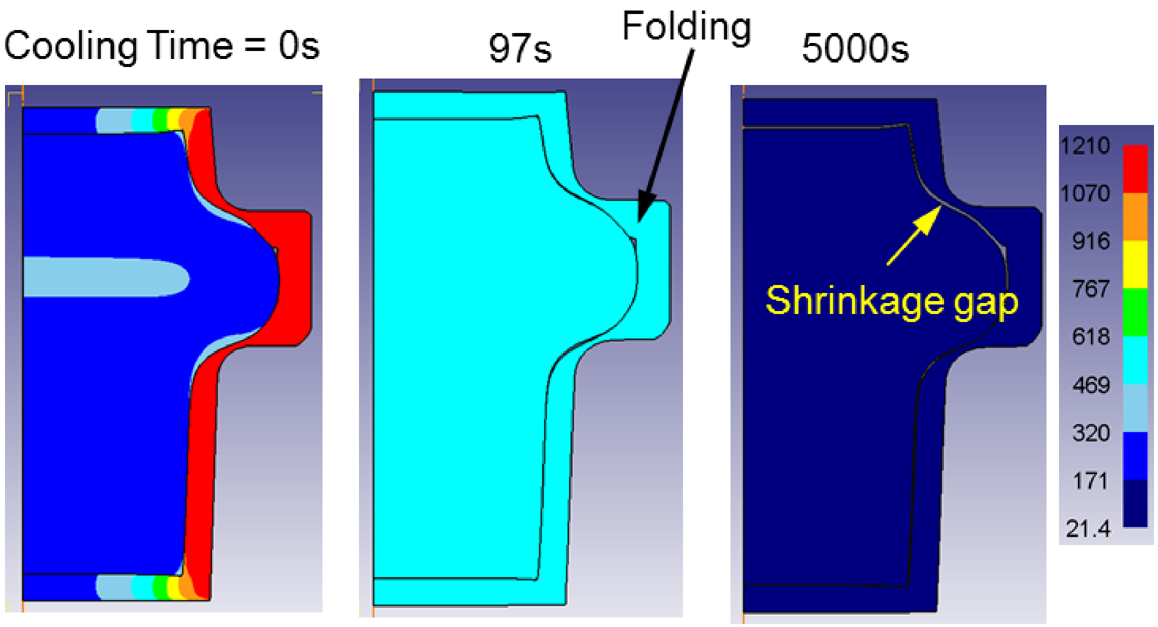
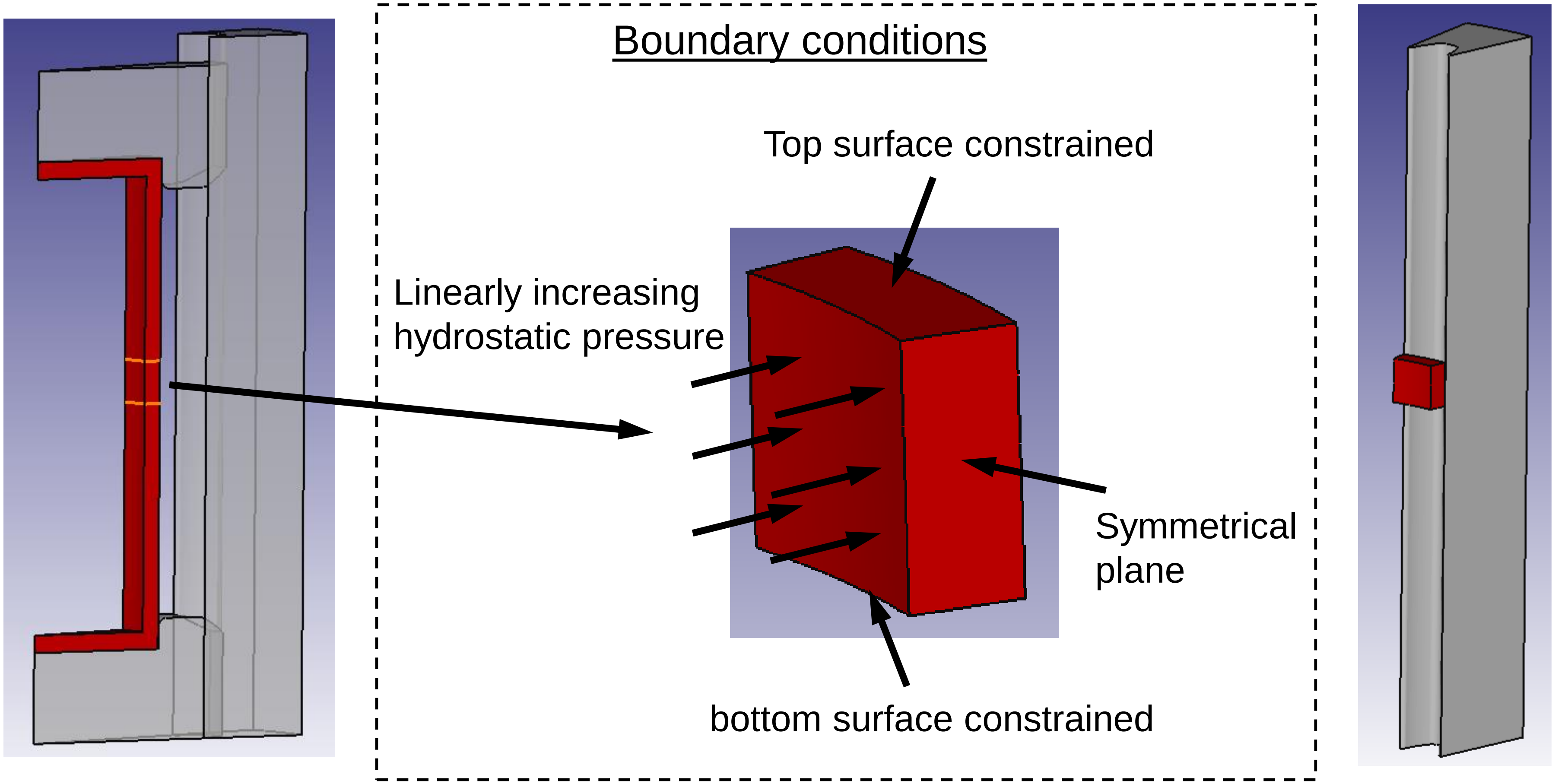
Solid state hot forging simulations

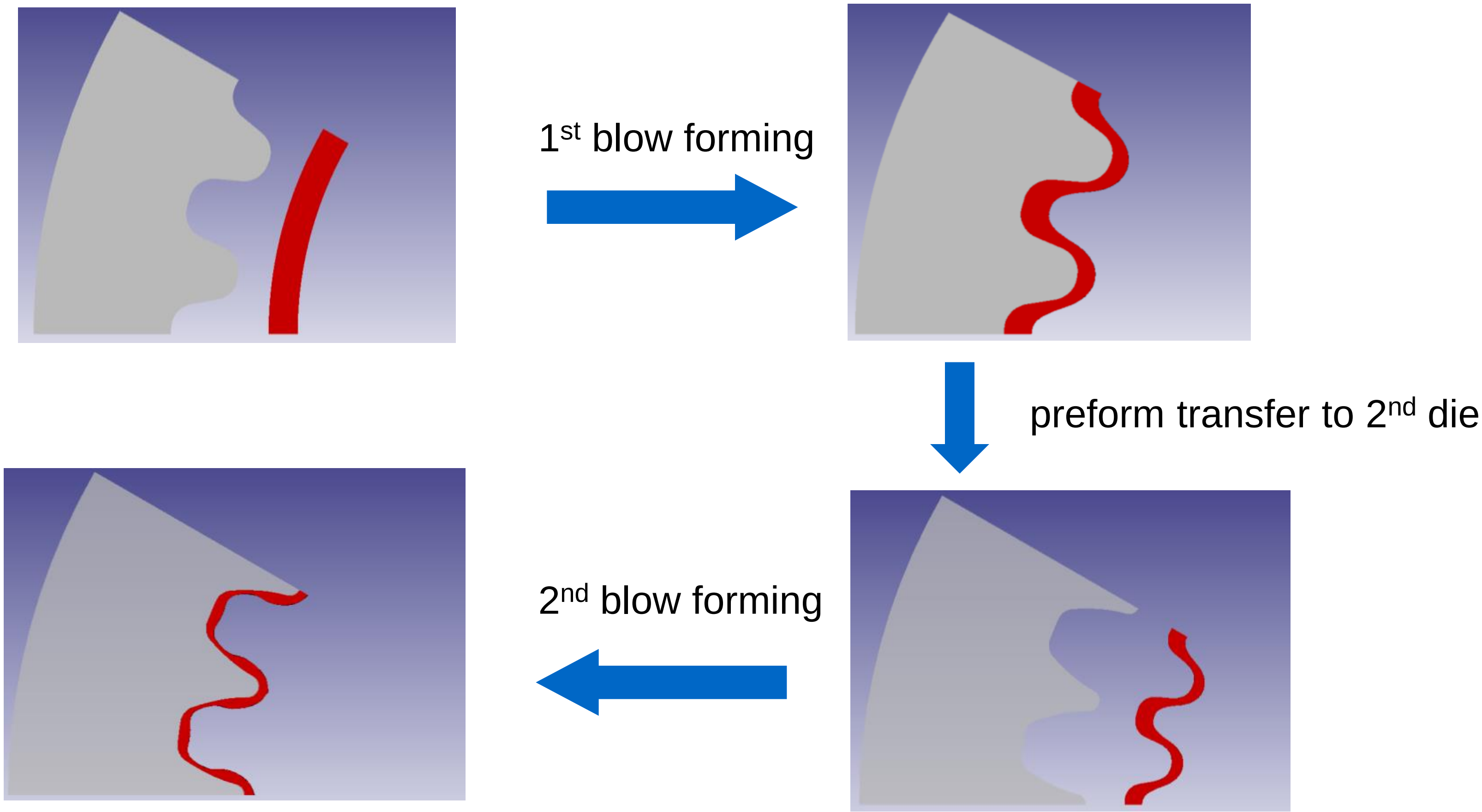


Solid state forging simulations predicted folds and shrinkage gap.

Steel wall thickness uniformity simulations with hot hydroforming

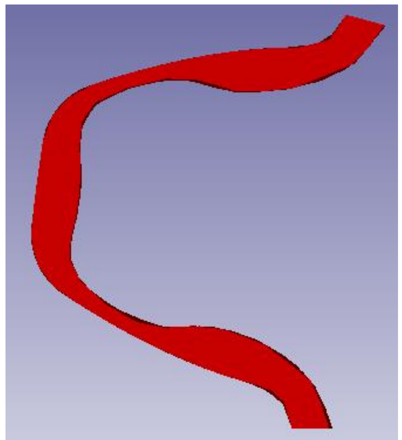
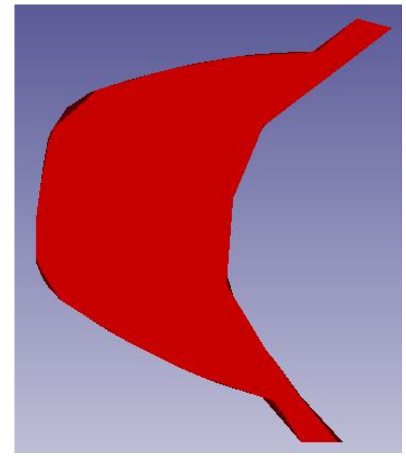


Concept: Two-blow hot hydroforming simulations for uniform wall thickness



The teeth profile is formed half way in the first die (top). The preform is indexed by half width of tooth and placed in the second die for final forging (bottom).

Tooth profile wall uniformity comparison

2 blow operation with hydrostatic pressure	1 blow operation Solid state forging simulation
	

Non-uniformity index	1.3	6.7
Al-steel ratio	2.7	0.6

- Non-uniformity index : largest thickness / smallest thickness. **1** means ideal uniform.
- Al - steel ratio: area of the Al / area of the steel in the tooth.

The steel wall thickness uniformity can be improved significantly with 2-blow, indexed, hot hydroforging as compared to 1-blow solid state forging

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Forging Trials at Walker Forge

Interpower Induction 10 kHz heater installed at Walker Forge

Walker's Erie 4000 ton mechanical press

Bi-Metal billets before forging

Heating

Transferred to the die

Right after forging

A few seconds after forging

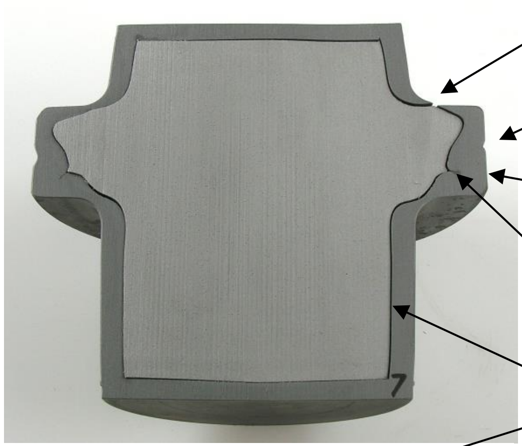
Forged parts

Comparison of hot forging and hot hydroforging experiments

Solid state hot forging

Steel @1100C

Al core @400C



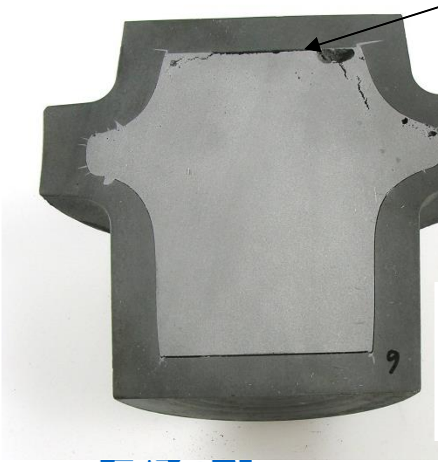
Fractured wall

Incomplete fill

Non-uniform wall

Fold

Gap due to CTE mismatch



Cracks

World's 1st Hot hydroforging

Steel @1100C

Al core @1100C

Void due to CTE mismatch

No fracture or crack

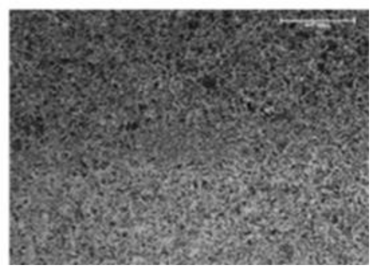
Uniform wall

Hot hydroforging is promising if CTE mismatch is eliminated

Weld zone healing in hot hydroforging


Before forging

Dentritic structure

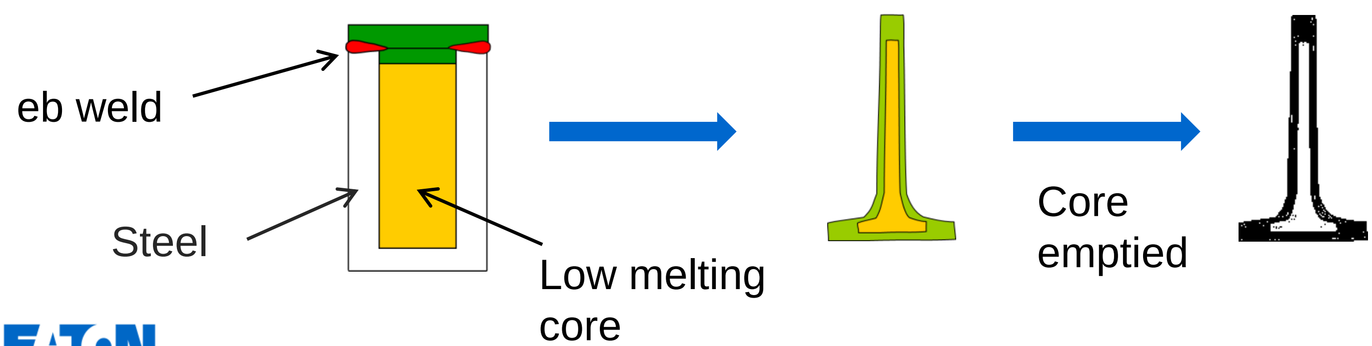
After busting hot hydroforging

Normalized structure

Dendritic structure of weld zone disappeared after hot hydroforging

"Investment Forging"

- Investment forging is a term coined at Eaton.
- It describes a process where the molten core is evacuated from the forged part after a hot hydroforging process leaving behind a hollow part.
- Investment forging provides the ultimate weight reduction up to 50% for a gear.
- Investment forging can also be applied to many other forged parts. For example forged hollow engine exhaust valves can be created by investment forging.



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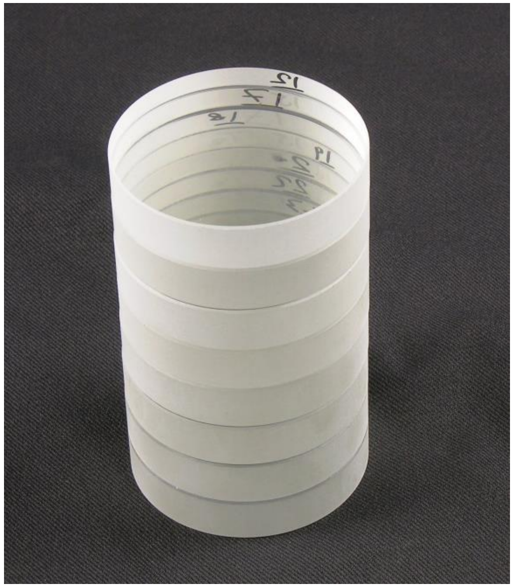
Eliminating CTE Mismatch with Glass

- Glass is identified as the core material of choice with matching CTE to that of steel, 10-12 (10^{-6} m/mK).



- The other advantages of glass:
  - Low cost
  - Low density
  - Good bonding to steel
  - Lower elastic modulus than steel
  - Working temperature can be optimized
  - May enable and temper a through-hardened steel wall

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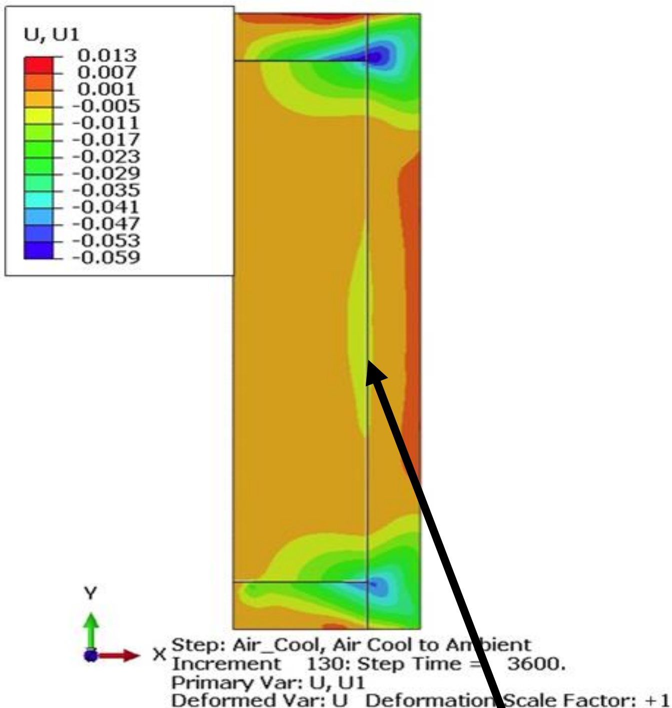
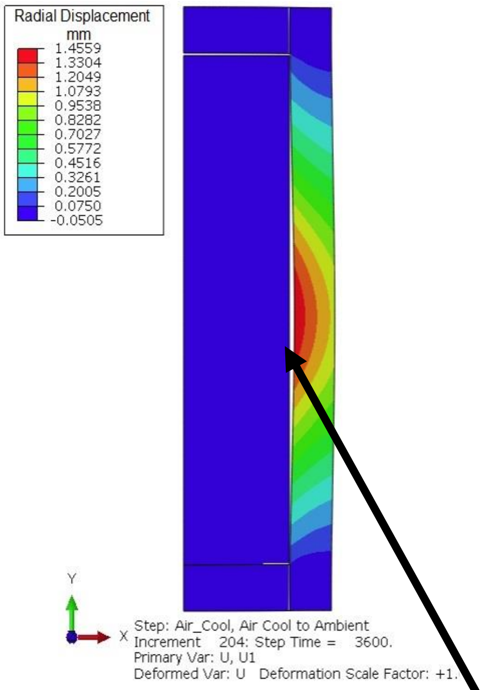
Heating/cooling simulations of hybrid billets, Displacement and gap formation in solid state

Steel/Glass



No gap predicted

Steel/Aluminum



Significant gap predicted

Glass is a promising lightweight core material.

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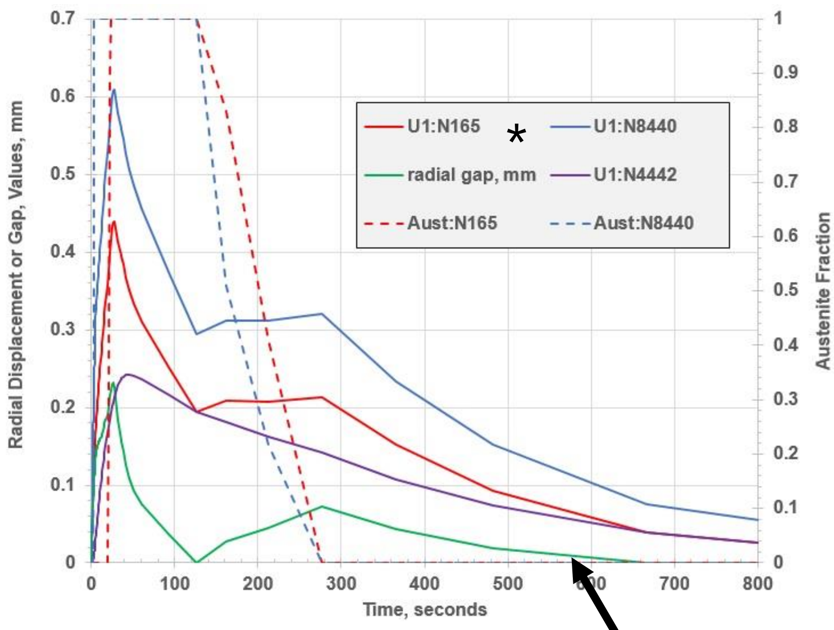
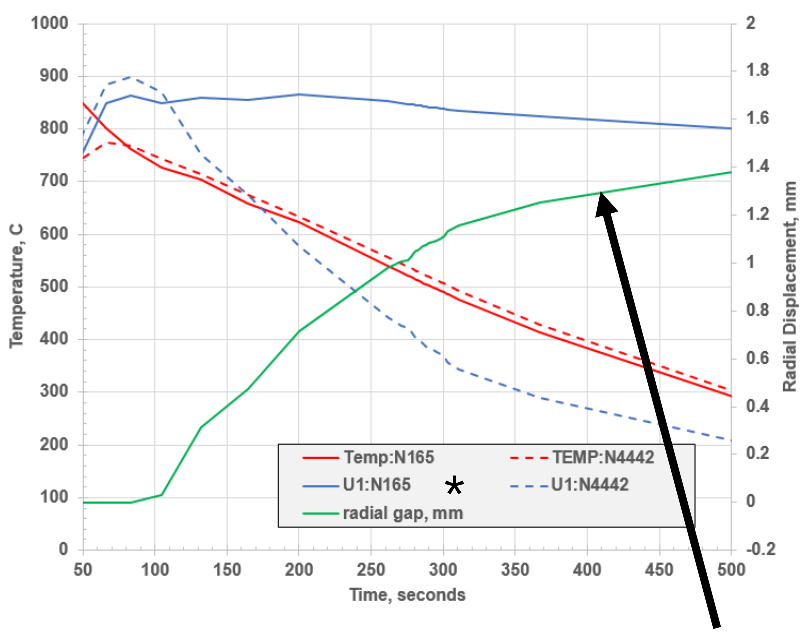
Histories of temperature, radial displacements and radial gap

Steel/Glass



No gap predicted

Steel/Aluminum



Significant gap predicted

* N165 is on steel bore, and N4442 is on outer surface of core.

Conclusions

- Feasibility of hot hydroforging and investment forging for lightweighting, net shape forging and waste reduction are demonstrated.
- Steel/aluminum hybrid billets were prepared. Then, the billets were hot hydroforged in closed dies.
- A uniform steel wall thickness was observed all around the hot hydroforged part upon cross sectioning.
- Weld seams are healed (normalized) upon hot hydroforging.
- Steel/glass is a more promising hybrid than steel/aluminum for hot hydroforging due to the CTE match.

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DRAFT REPORT

U.S. DEPARTMENT OF ENERGY

VEHICLE TECHNOLOGIES PROGRAM

WORKSHOP REPORT:

Trucks and Heavy-Duty Vehicles
Material Technical Requirements and Gaps

July 2012

DRAFT REPORT

Light Duty Truck and SUV Cab and Body(including interior) Targets (Relative to 2010 Baseline)

	2020	2025	2030	2040	2050
Weight Reduction of cab and body	25%	35%	45%	50%	55%
Cost Penalty	10%	10%	10%	20%	20%
Fuel Based Cost Tolerance $/lbs. saved	$3.24/lbs. Saved	$3.42/lbs. Saved	$3.60/lbs. Saved*	$3.96/lbs. Saved*	$4.32/lbs. Saved*
Stiffness and NVH	Match Baseline	Match Baseline	Match Baseline	Match Baseline	Match Baseline
Durability	Match Baseline	Match Baseline	Match Baseline	Match Baseline	Match Baseline
Production time	Match Baseline	Match Baseline	+10%	+20%	+10%
Synergies	Automotive Body (Metal) & Interior	Automotive Body (Metal) & Interior	Automotive Body (Metal) & Interior	Automotive Body (Composites) & Interior	Automotive Body (Composites) & Interior

Heavy-Duty Truck Cab and Body(including interior) Targets (Relative to 2010 Baseline)

	2020	2025	2030	2040	2050
Weight Reduction of body and cab	15%	35%	45%	55%	60%
Cost Penalty	Match Baseline	<10%	<10%	<20%	<20%
Fuel Based Cost Tolerance $/lbs. saved	$3.97/lbs. Saved*	$4.15/lbs. Saved*	$4.33/lbs. Saved*	$4.69/lbs. Saved*	$5.05/lbs. Saved*
Stiffness and NVH	Match Baseline	Match Baseline	Match Baseline	Match Baseline	Match Baseline
Durability	Match Baseline	Match Baseline	Match Baseline	Match Baseline	Match Baseline
Production time	Match Baseline	Match Baseline	+10%	+20%	+10%
Synergies	Automotive Body (Metal) & Interior, Marine (Composites)	Automotive Body (Metal) & Interior, Marine (Composites)	Automotive Body (Metal) & Interior, Marine (Composites)	Automotive Body (Composites) & Interior	Automotive Body (Composites) & Interior