Introduction to Aluminum Use in Automotive

The Aluminum Transportation Group

Presenter

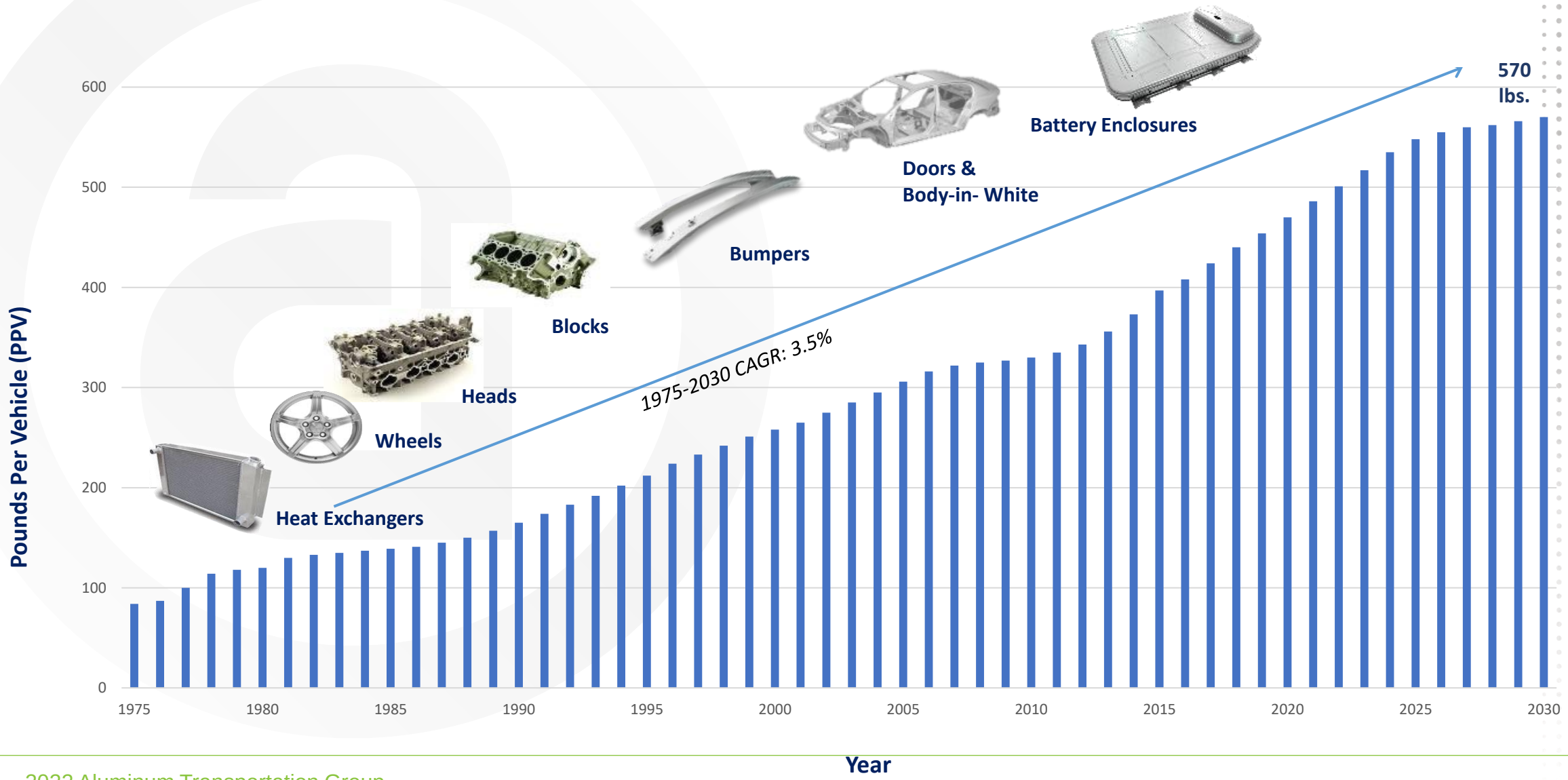
Debdutta Roy, Ph.D.

Novelis

Lead Scientist, R&D Automotive



55 YEARS OF AUTO DEMAND GROWTH



Source: DuckerFrontier

Aluminum Sheet Usage Still Small in Automotive





85.5 Mt Steel for automotive, 2016

2.2 Mt Aluminum sheet for automotive, 2020

1.4 Mt Aluminum sheet for automotive, 2017

LEARNING OBJECTIVES

- What are the needs of Automotive customers?
  - Understand Automotive material evolution
  - Explain the Aluminum advantage in transportation
    - Emissions/CAFÉ/Light Weighting
  - List key product requirements
  - Describe Automotive customer processing
  - Wrought sheet production route and microstructure correlation
- Describe technical solutions that aluminum can offer
  - 5xxx and 6xxx alloys
  - New developments
  - Future challenges

Automotive Materials Evolution

ALUMINUM HAS COME A LONG WAY……



a



b

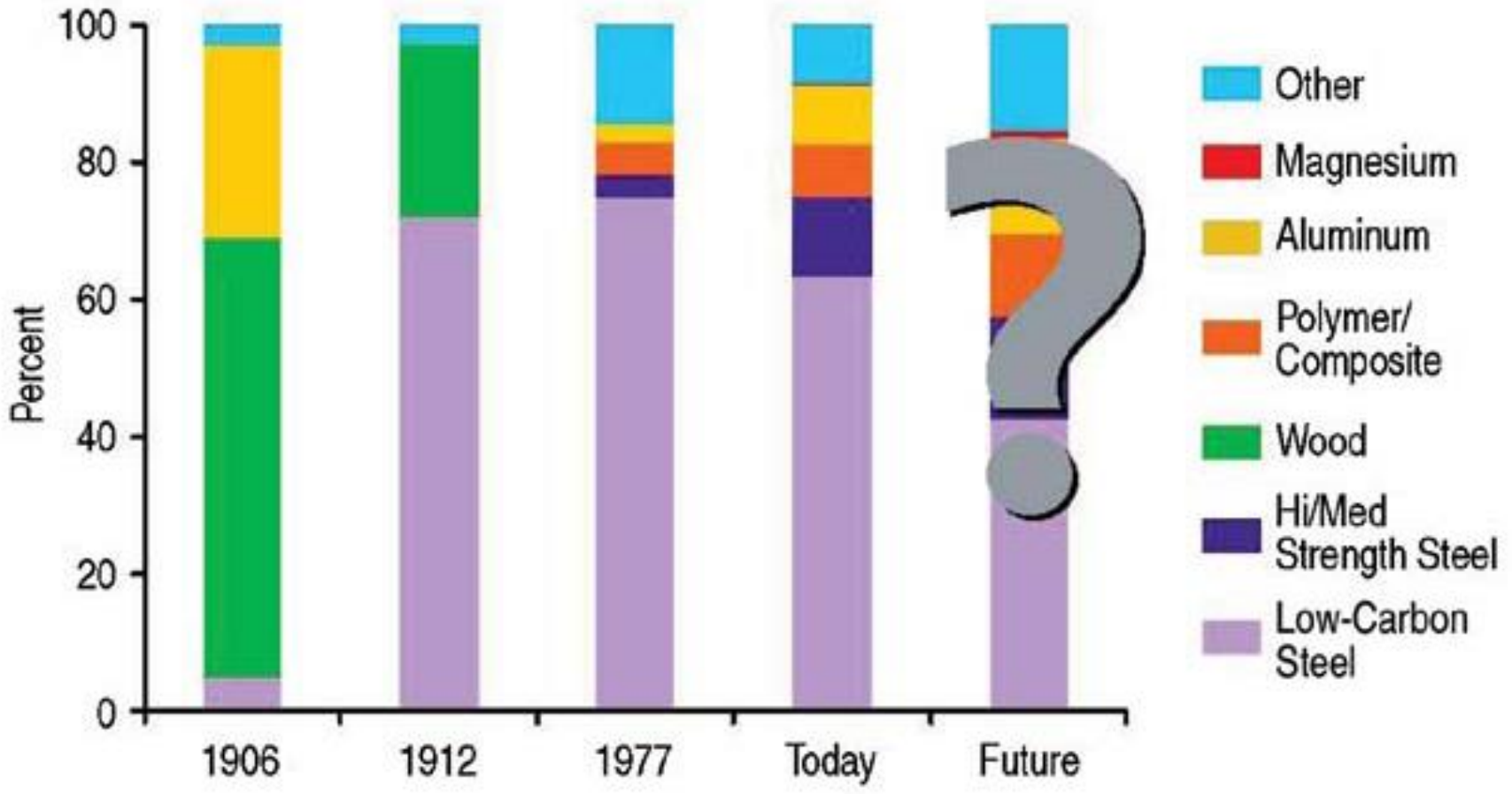


(a) A 1909 Ford *Model T Touring Car with* aluminum closure panels and

(b) Aluminum hood from 1915 *Model T (Source: JOM* 2007 February)

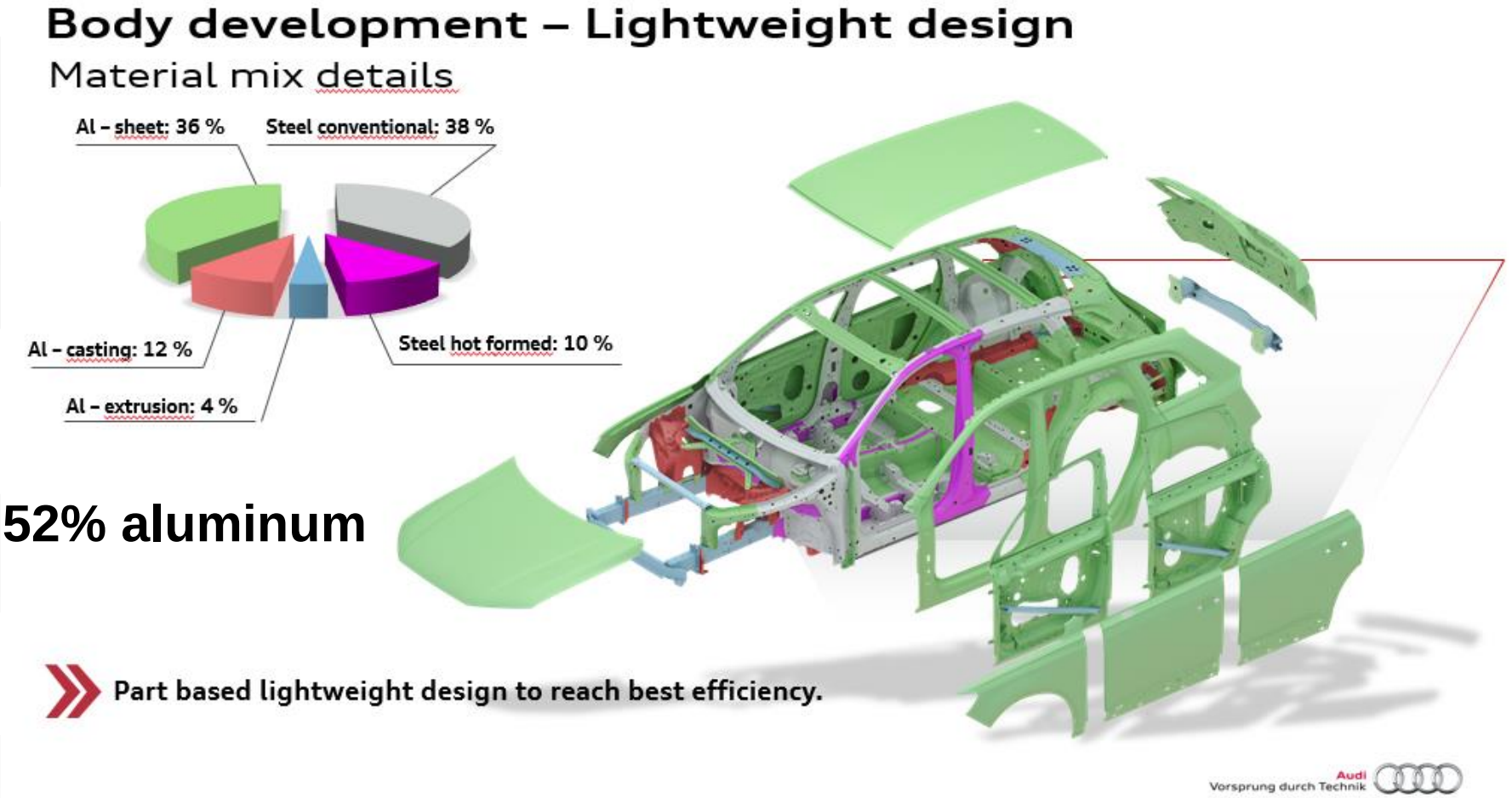
Audi A8 D2 1993

MATERIALS IN A TYPICAL AUTOMOBILE - HISTORICAL PERSPECTIVE



- 1900's First cars
- 1910 – 1940 Mass production
- 1993 – Audi A8 Full Al car
- Actual trend : Mixed Material

2016 Audi Q7 – Hybrid Steel/Aluminum



48% steel / 52% aluminum

The Aluminum Advantage

ALUMINUM | THE VIRTUOUS CYCLE

Mass Reduction





Better Fuel Economy

Reduced Emissions



Improved Safety





Enhanced Performance

Infinitely Recyclable



CAR WEIGHT



1974: birth of the Volkswagen Golf

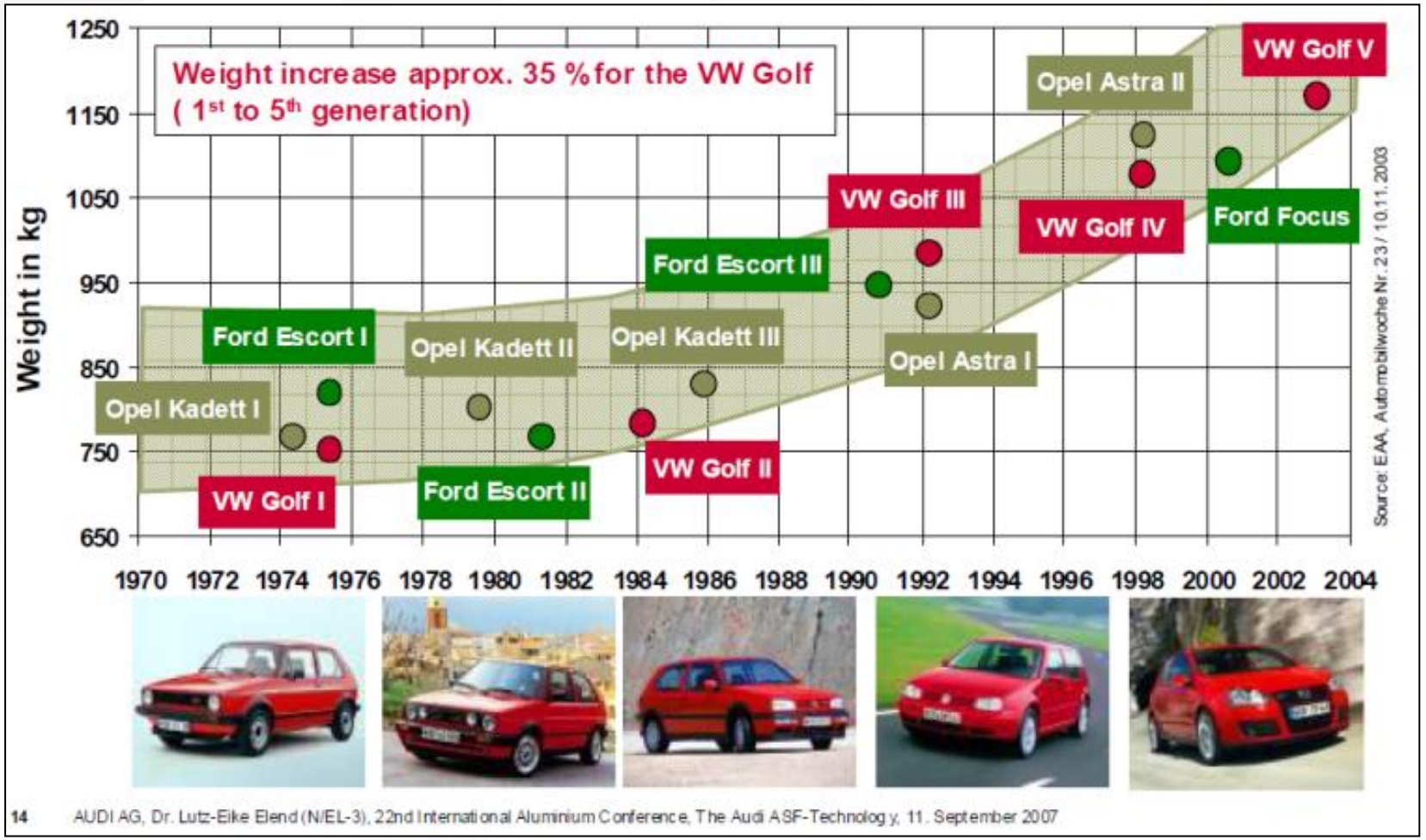
What was the weight of this car ?

(Full steel Body)

Use the chat to type your response

EVOLUTION OF WEIGHT IN COMPACT-CARS CLASS …

in 40 years and 25 millions Golf later



2008: VW Golf VI 1.4



Weight: 1215 kg

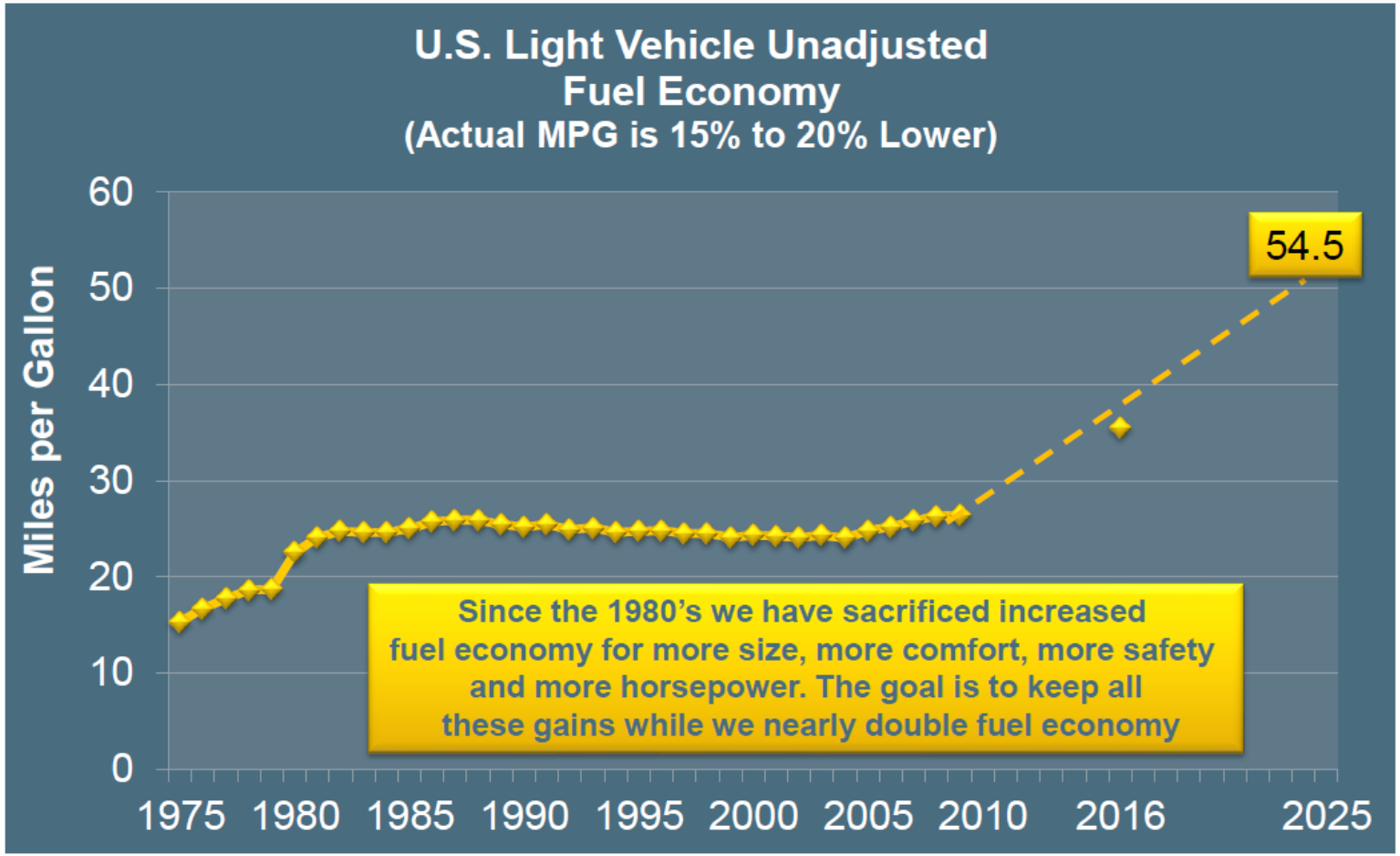
2012: VW Golf VII



Weight: 1130 kg

NEW CAFÉ STANDARDS

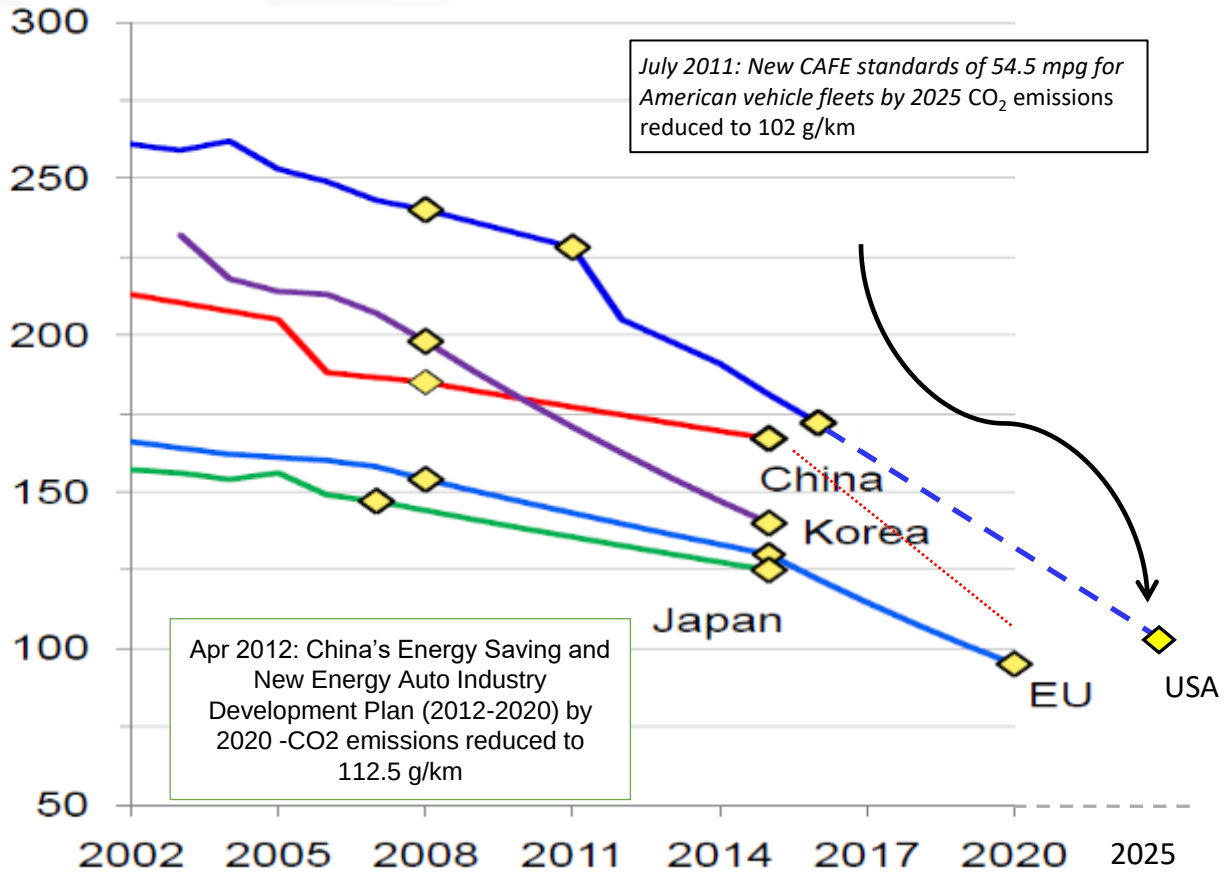
Both the OEMs and consumers appear to be ready to accept the challenges and costs required to drive U.S. fuel economy to unprecedented levels



(Source: Ducker Worldwide, 2012)

LEGISLATION TRENDS WORLDWIDE

Auto CO_2 Emission Trend (in g/km)

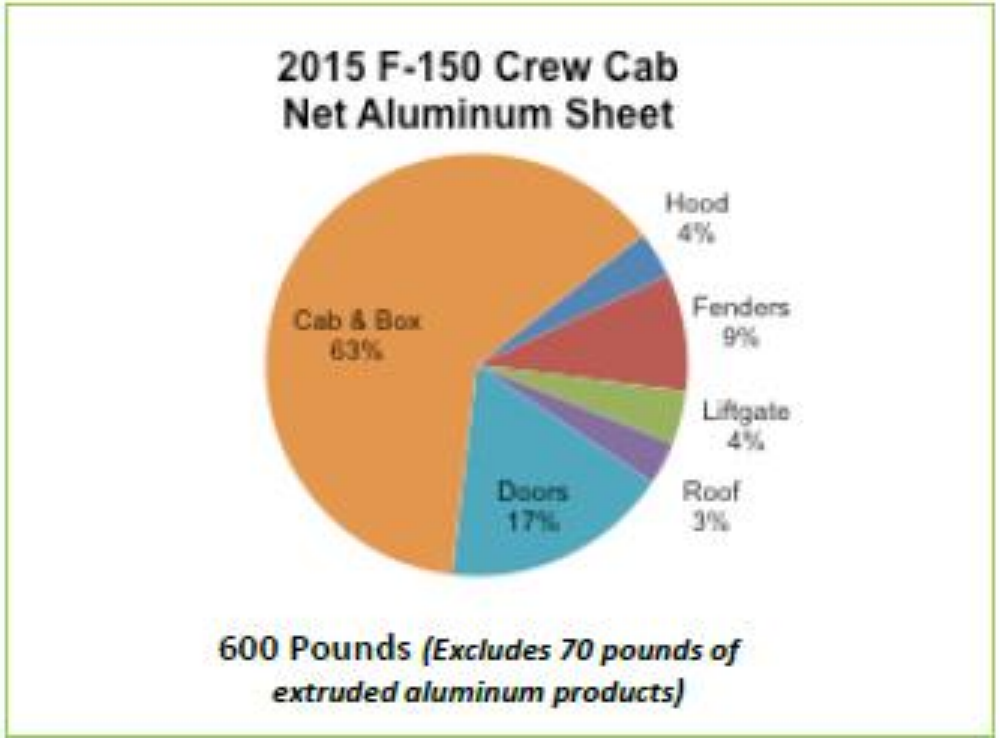


Source: International Council on Clean Transportation (ICCT)

ALUMINUM TO REPLACE STEEL

- To achieve < 130 gmCO2 per Km, the curb weight must drop
- Total vehicle weight savings target 300-800 kg
- BIW will be the main contributor to achieve this overall reduction
  - **High Strength Steel** for down gauging : 10% reduction weight possible
  - **Aluminum part substitution** : 40% reduction weight possible





Customer Processing

OEM Production Process

Other

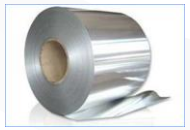
Castings



Extrusions



Rolled Sheet



Forming



Joining



BIW Pretreatment



Painting

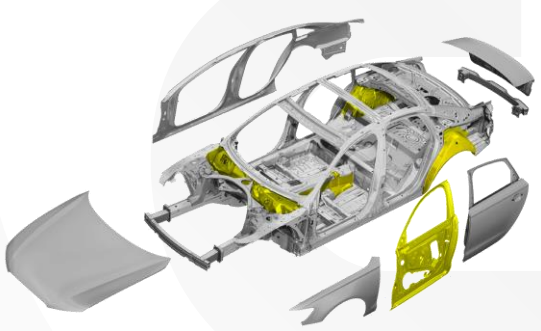


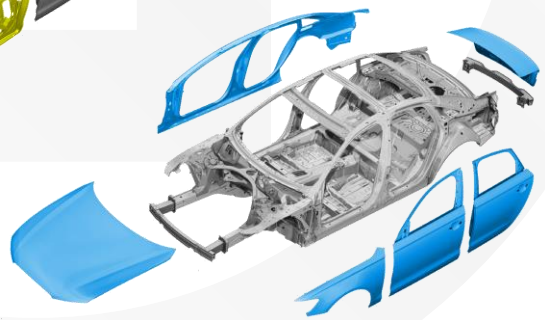
- Most of the vehicle Body-in-White (BiW) is made from stamped sheet metal parts
- Depending on the application, different material properties are required and can pose different challenges during stamping

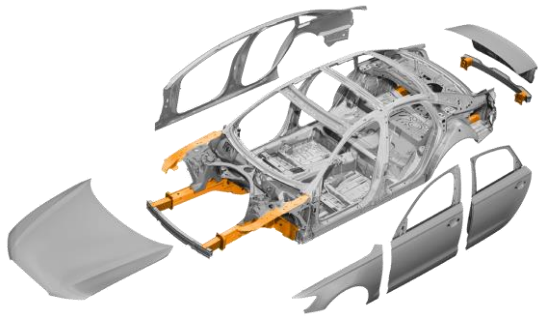
Key product requirements

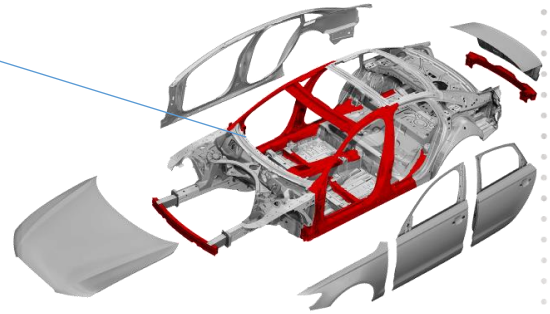
ALUMINUM SHEET APPLICATION MAP

General Inners	General Outers	Safety Cage / BIW

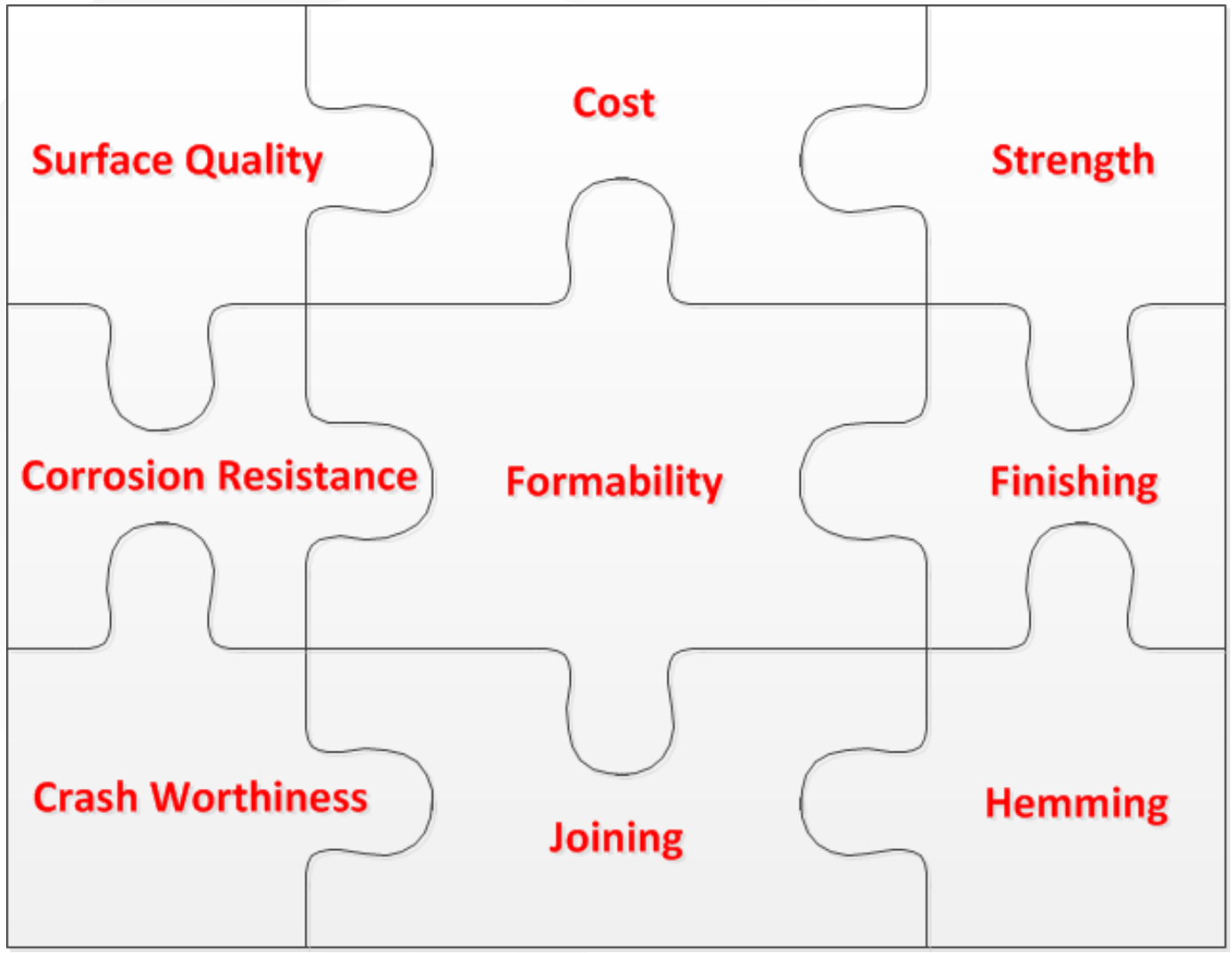








SOLVING ALLOY "PUZZLE" TO MEET CUSTOMER NEEDS



- **Start with requirements for a given application**
- **COST is usually a large piece of the puzzle**
- **Expect property trade-offs**
- **Select alloy composition and processing to solve the puzzle.**

IMPORTANCE OF STRENGTH

Increasing strength allows to down-gauge panels (as long as stiffness requirements are met)





What are benefits of downgauging?



Use the chat to type your response

IMPORTANCE OF STRENGTH

Increasing strength allows to down-gauge panels (as long as stiffness requirements are met)

Down gauging is directly proportional to:

- **Weight saving**



- **Cost saving**







Automotive Crash Requirements















Protection is not only meant for occupant but also for pedestrians.

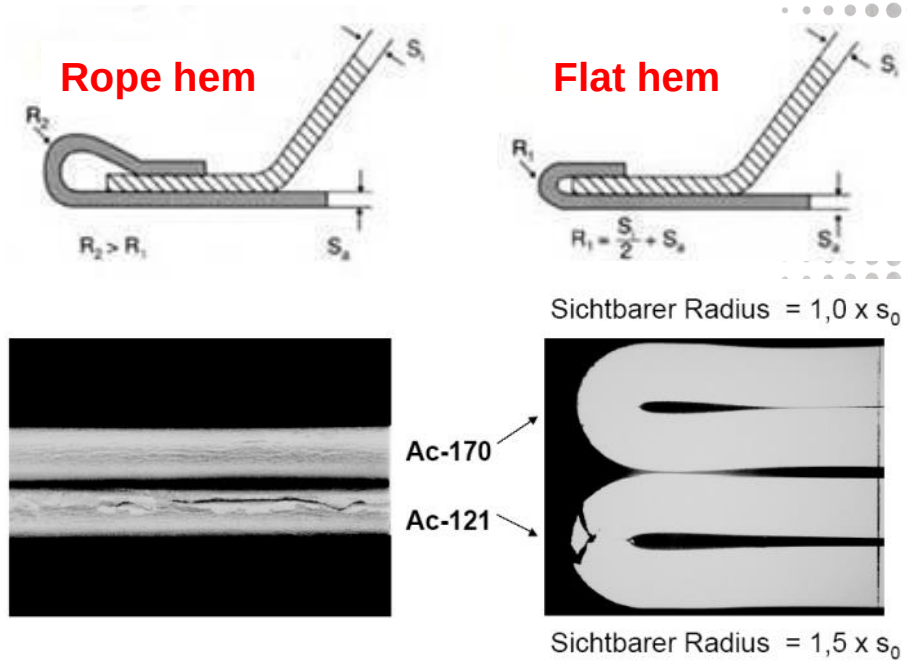
Occupant protection- energy absorption, high strength, high fracture toughness. Such as high strength 6xxx and 7xxx alloys.

Pedestrian protection- soft alloys such as 6xxx alloys.

REQUIREMENTS FOR ALUMINUM USE IN AUTOMOTIVE

Example 1: hood

- High strength: down gauging, dent resistance
- Bendability: hemming (assembly)
- Formability: design
- Energy absorption: pedestrian safety
- Surface quality: large flat visible surface
- Corrosion resistance



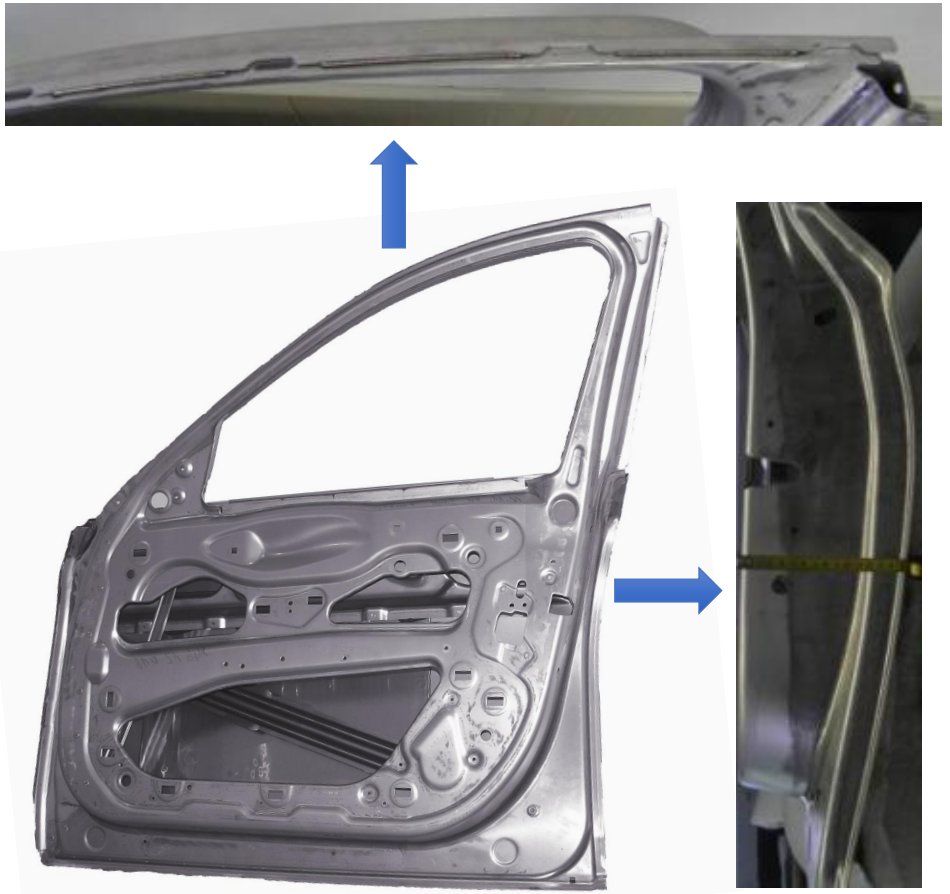




REQUIREMENTS FOR ALUMINUM USE IN AUTOMOTIVE

Example 2: door inner panel

- High formability: deep drawing
- Weldability: frame assembly
- Corrosion resistance



OEM Specific Designations

- Most Auto OEMs purchase to one of their internal specifications
- For example: Ford

Ford Spec	Typical Application	AA Designation
6EH	6xxx outer panel with enhanced hemming	6022, 6014
6DR1	6xxx exterior or interior	6022, 6016
6HS2	6xxx high strength	6111
6ST1	Alternative high strength	6061
5HF	5xxx High form	5182
5ST	5xxx standard	5754

ALUMINUM ALLOY, SHEET, HEAT TREATABLE, STRUCTURAL, HIGH STRENGTH, THIN GAGE	WSS-M2A175-A1
ALUMINUM ALLOY, SHEET, HEAT TREATABLE, STRUCTURAL, HIGH STRENGTH, THICK GAGE	WSS-M2A175-A2
ALUMINUM ALLOY, SHEET, HEAT TREATABLE, STRUCTURAL, HIGH STRENGTH, LOW COPPER	
ALUMINUM ALLOY, SHEET, HEAT TREATABLE, STRUCTURAL, ENERGY ABSORPTION	
ALUMINUM ALLOY, SHEET, HEAT TREATABLE, STRUCTURAL, OVERAGED	

Table 2: Mechanical Properties (minimum, unless shown as a range or maximum)

	A1	A2	A3	A4	A5
Yield Strength, MPa (0.2% offset)	125 - 165	140 - 185	125 - 170	170 - 210	83 max
Yield Strength at 180 days*, MPa, max	175	195	180	210	N/A
Ultimate Tensile Strength, MPa	230 - 290	240 - 300	230 - 290	240 - 290	152 max
Uniform Elongation, %	19	19	19	15	N/A
Total Elongation, %	N/A	N/A	N/A	N/A	15
r_{avg}	0.50	0.50	0.50	0.50	N/A
r_{45}	0.30	0.30	0.30	Report Only	N/A
Yield Strength Increase After T81, Mpa	30	30	30	N/A	N/A
Yield Strength (T82), MPa	260	260	260	N/A	N/A
Yield Strength (T72), MPa	N/A	N/A	N/A	N/A	200
Bendability After T82, r/t, max	0.40	0.40	0.40	Report Only	N/A
Bendability After T72, r/t, max	N/A	N/A	N/A	N/A	0.30

Sheet Solutions 5xxx vs 6xxx automotive sheet applications

Overview of Aluminum Automotive Alloys

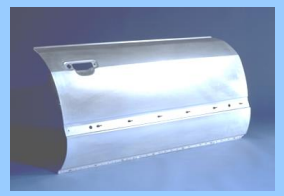
Body Structure Inner Panels



Attachments



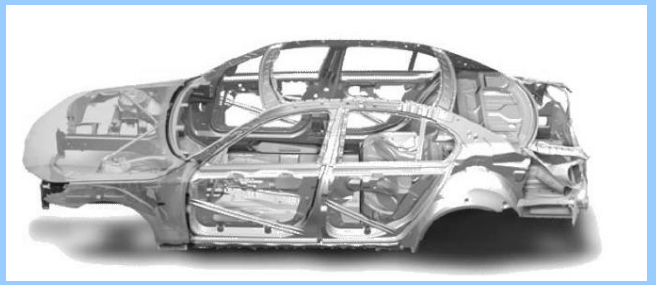






Body in White

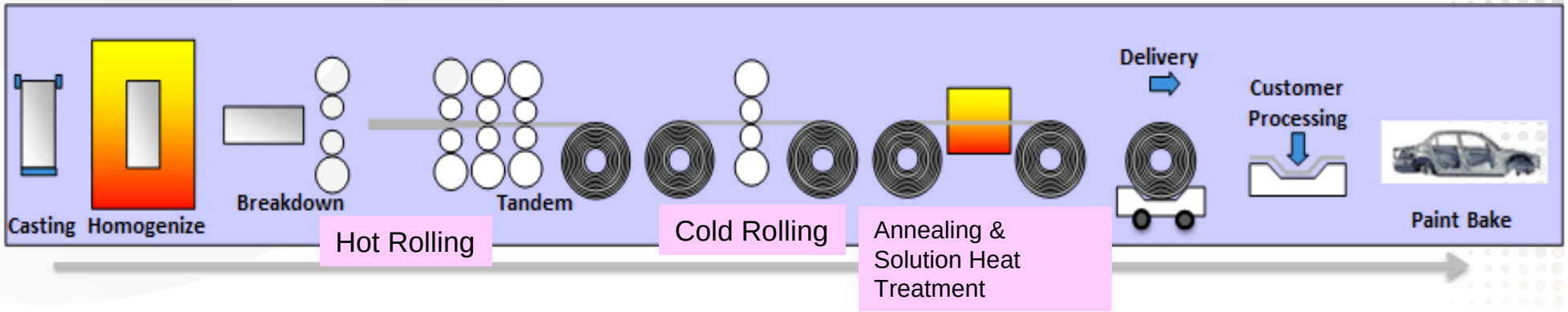




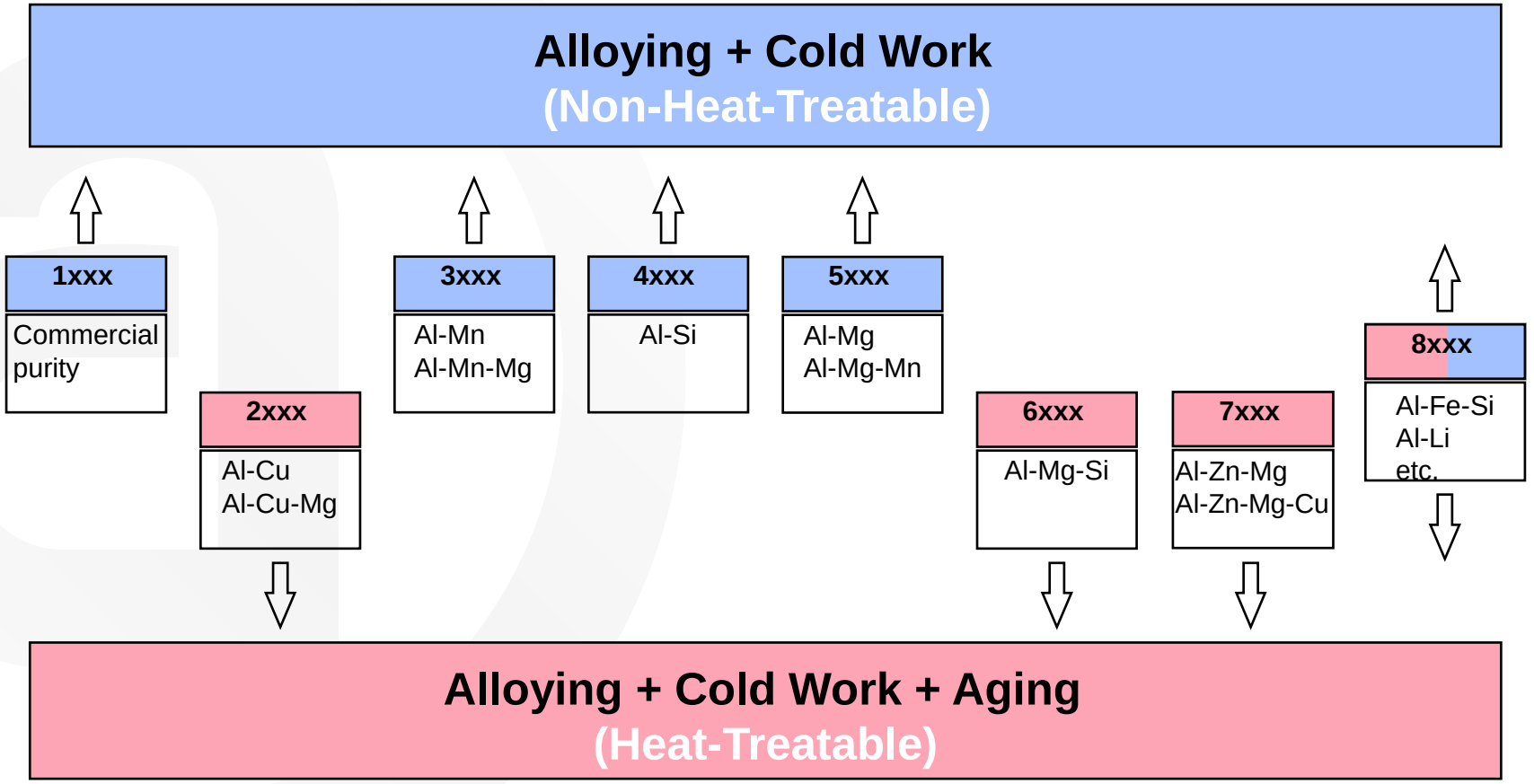
Application Requirements guide Alloy selection

- Heat Treatable (Precipitation Hardenable) 6xxx
- Non Heat Treatable 5xxx

Typical Process Flow



Precipitation Strengthening is Not Always Possible

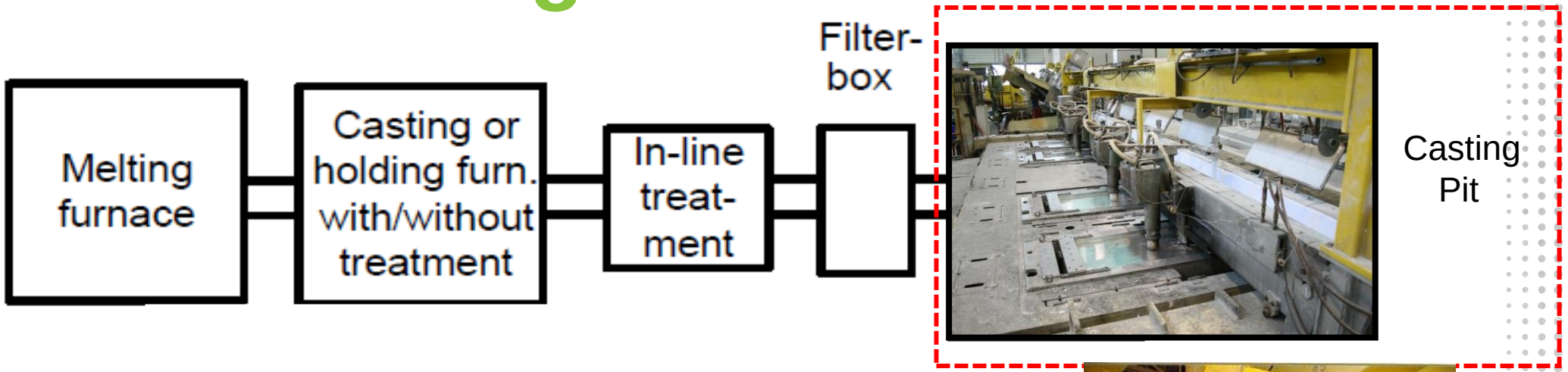


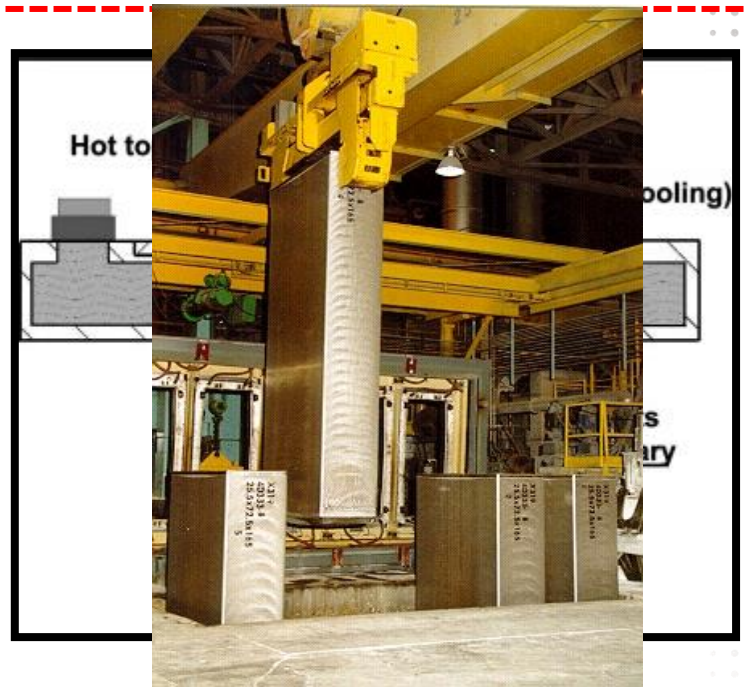
Homogenization & Hot rolling Video



https://www.youtube.com/watch?v=s-NPEAv3Zjw

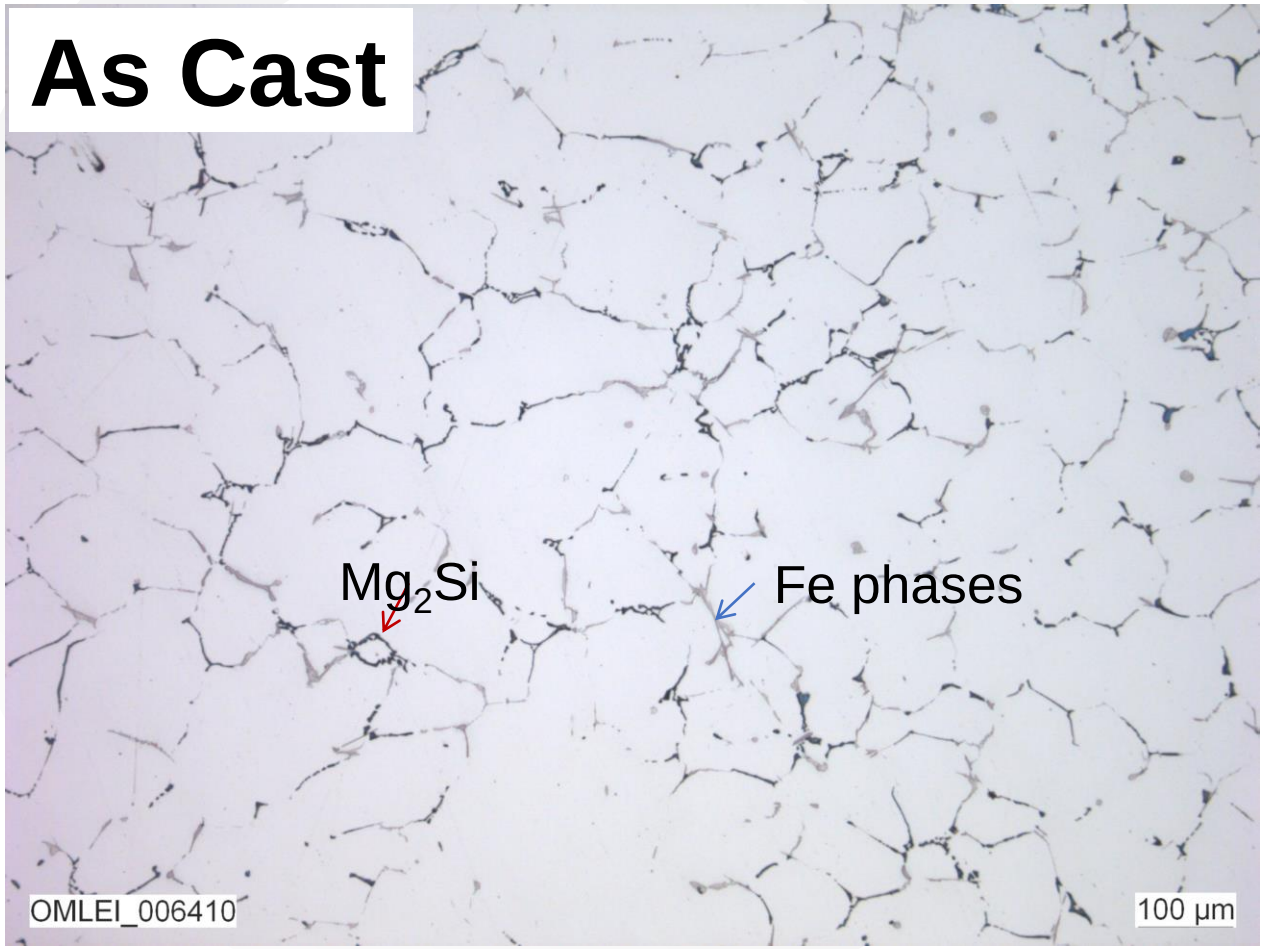
Direct Chill Casting

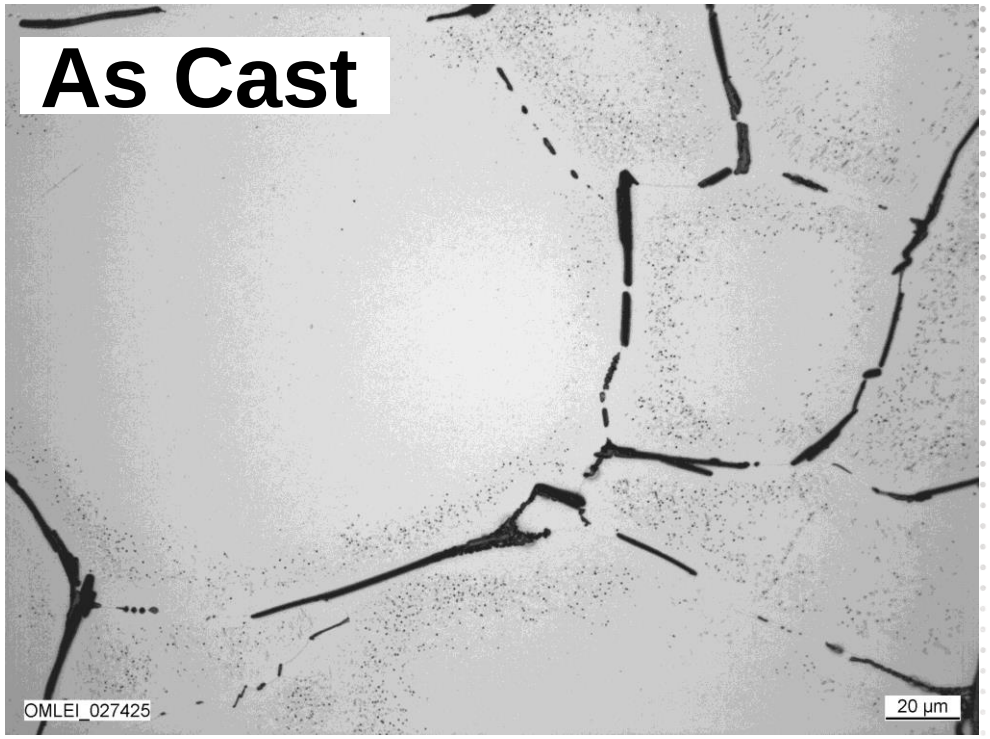




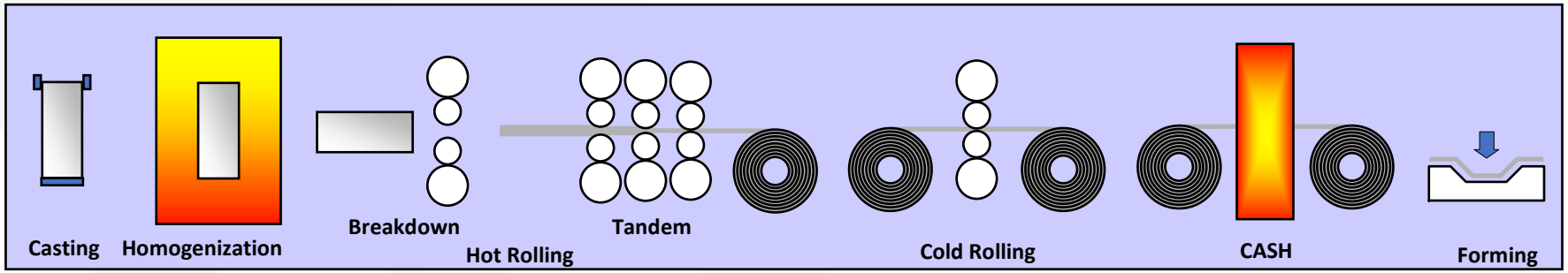
- **Direct chill (DC) casting technology is used to solidify the metal into an ingot**
  - **Molten metal flows into a cooled mold and begins to solidify**
  - **The bottom of the mold is lowered at a controlled rate to allow water to directly chill the solid Al shell**
  - **4 to 6 ingots can be cast at a time and can weigh 10-15 tons each**

As-Cast Microstructures



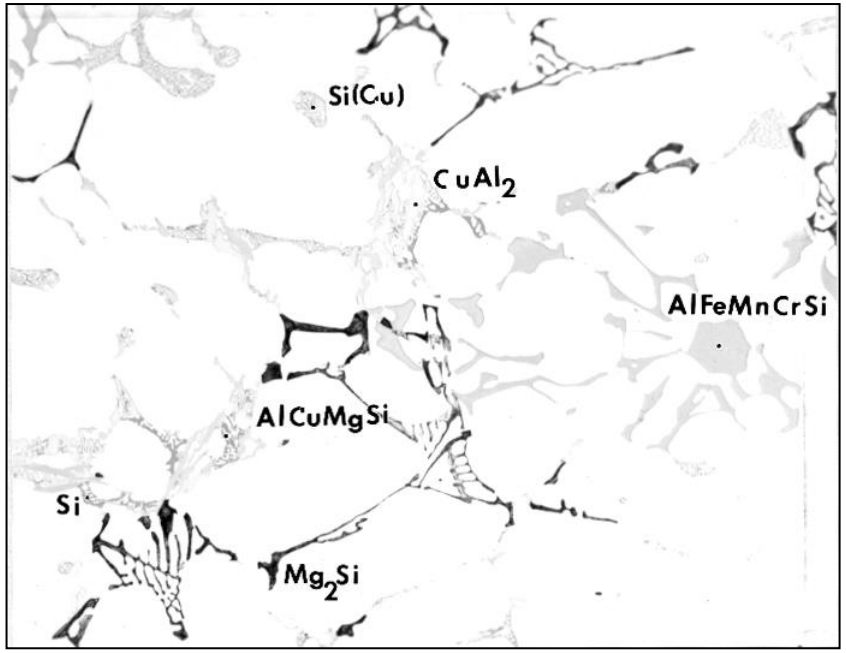


Homogenization - Purpose



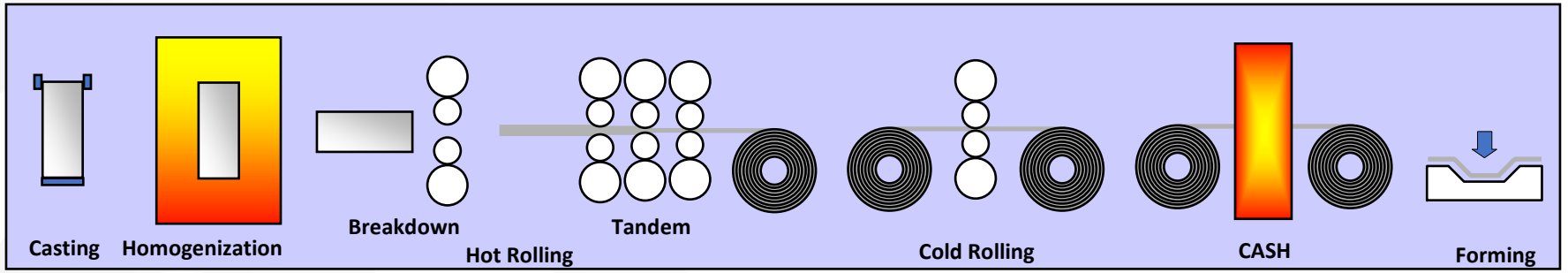
Purpose

- **Improve workability**
- **Eliminate coring – i.e. segregation of alloying elements**
- **Dissolve Mg_2Si particles**
- **Modify Fe phases**
- **Form dispersoid particles**
- But cannot alter inclusions and inverse segregation (which must be removed by scalping)



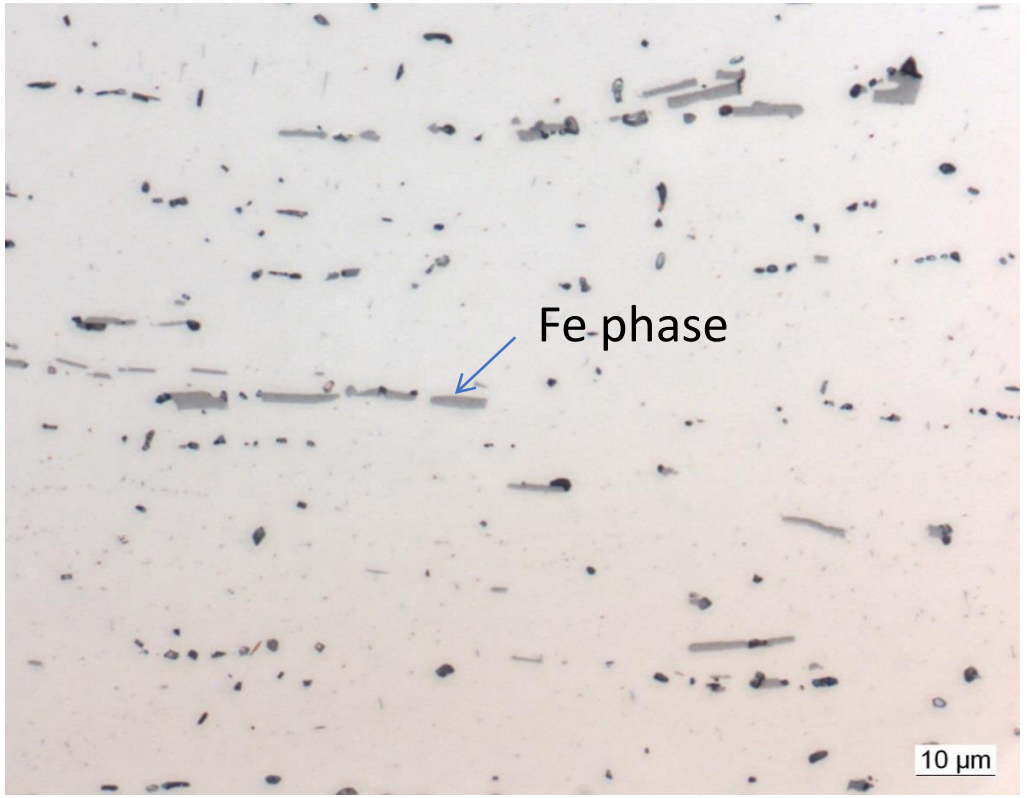
AA6xxx As-Cast Microstructure

Hot Rolling



Purpose

- Reduce the ingot thickness
- Break up large second phase particles
- Recrystallize grains to produce a randomly oriented crystal structure

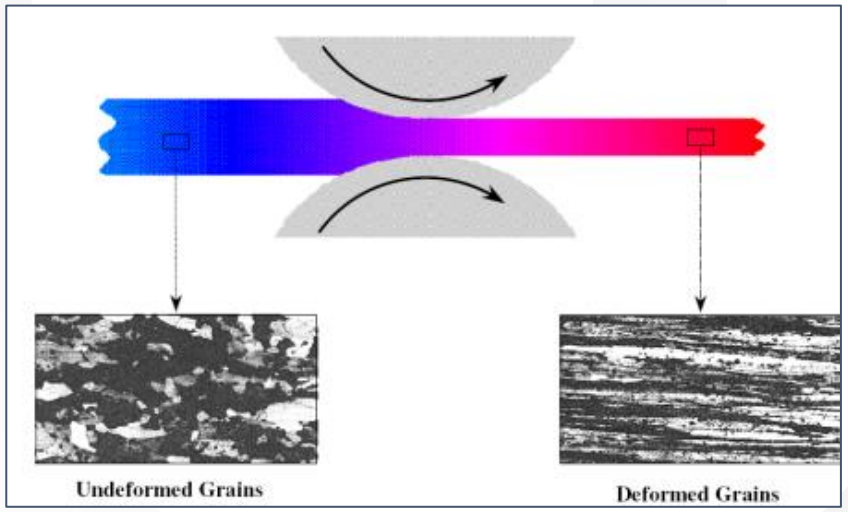


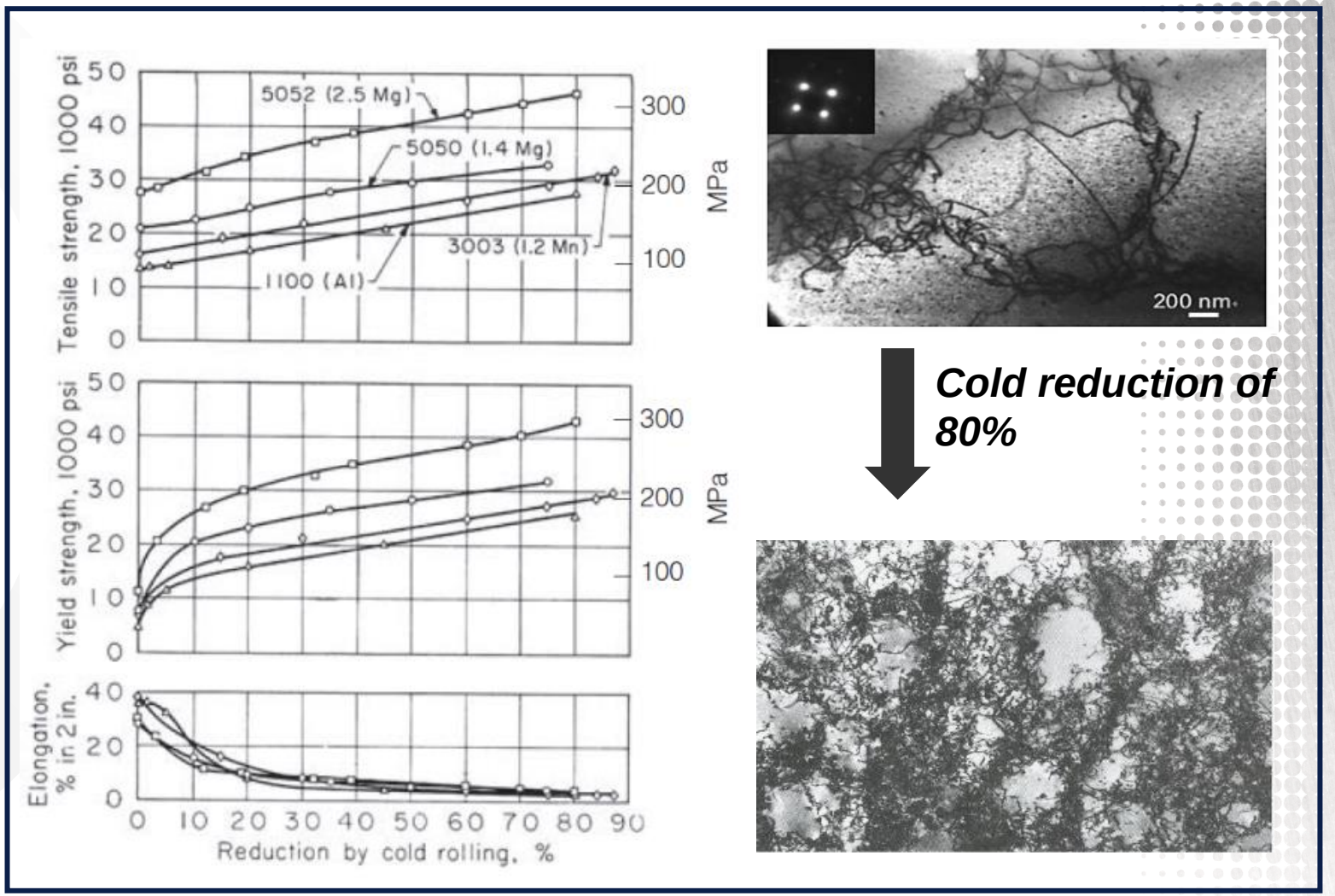
Cold Rolling

Cold Rolling defined as rolling below temperature for recrystallization (< 150°C).

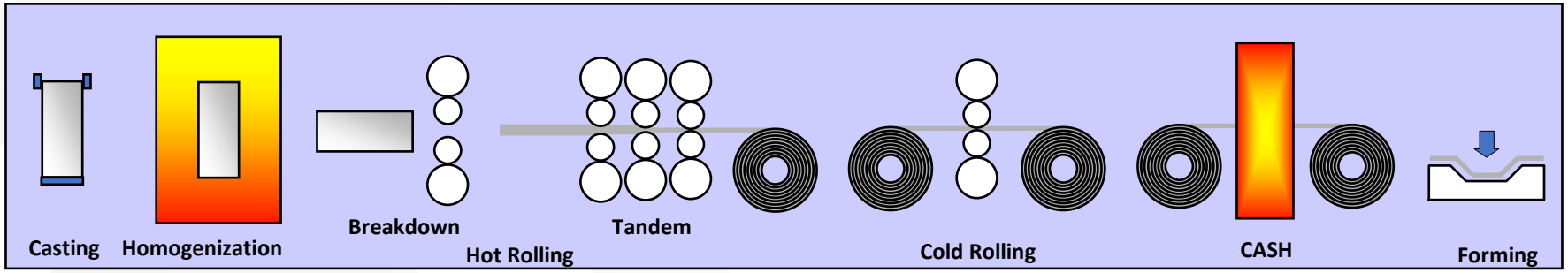
Purpose

- **Reduce the gauge down to final gauge**





Solution Heat Treatment



After cold rolling

- High strength
- Low ductility
- Soluble phases are precipitated

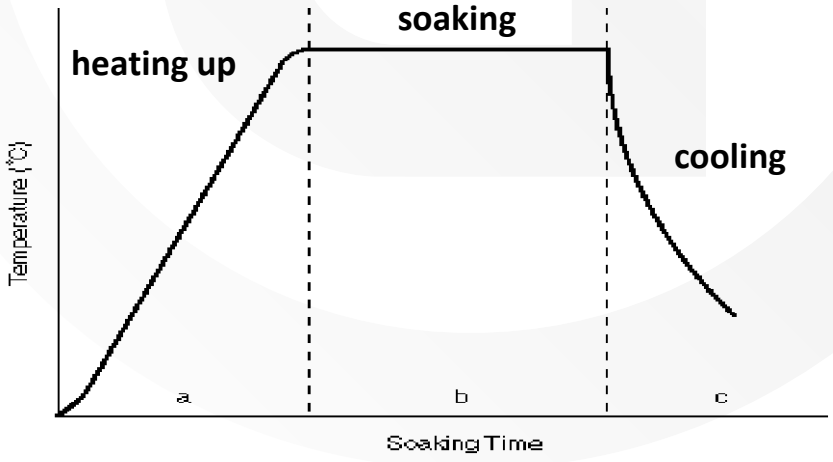
Annealing & Solution Heat Treatment

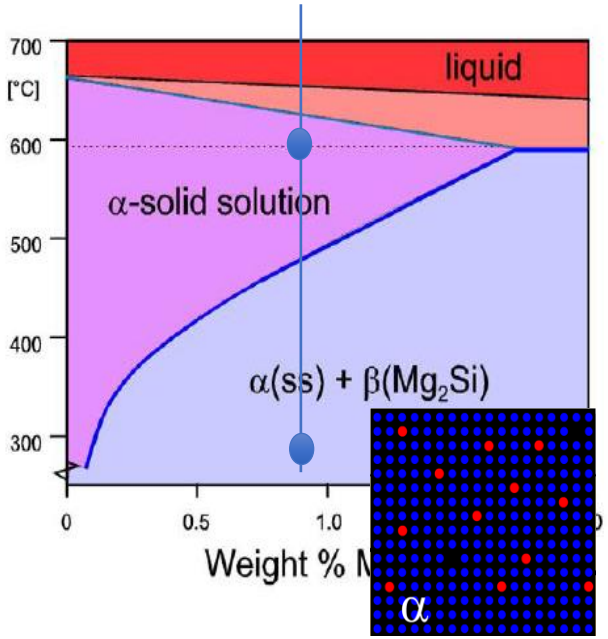
T4 material

- Soft
- Formable
- Hardening potential



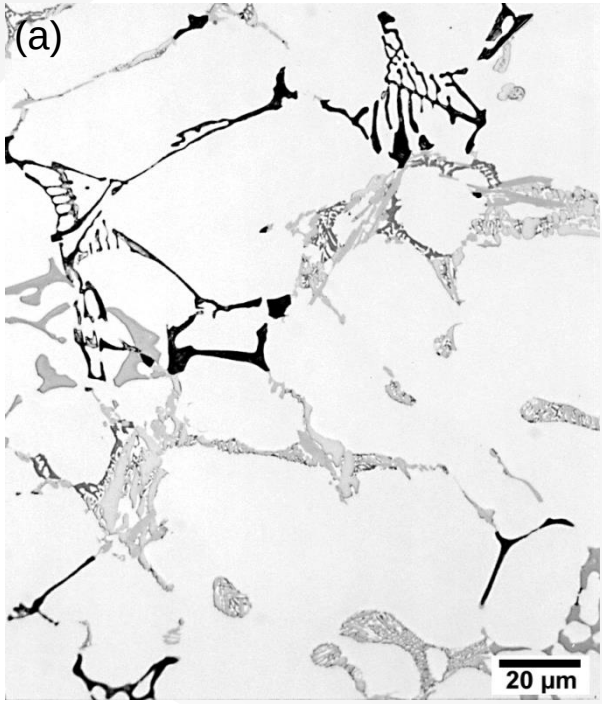
Schematic Figure of Solution Heat Treatment





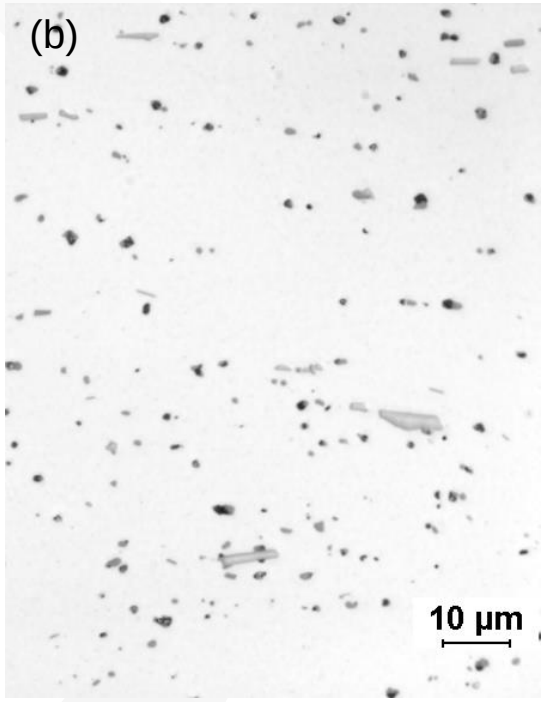
MICROSTRUCTURES OF AA 6XXX ALLOYS

As cast



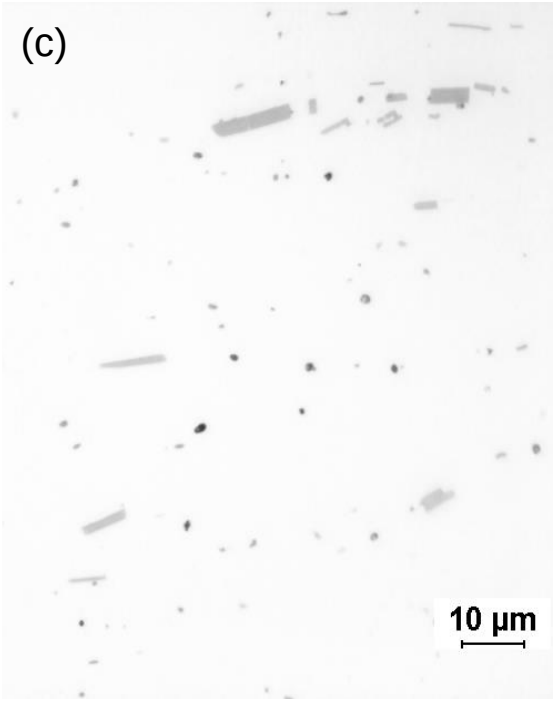
Coarse primary particles (Mg_2Si, β-Al_5FeSi, AlCuSi in Cu containing alloys) at the as cast cell boundaries

As rolled final gauge



High density of intermetallic particles: Mg_2Si and AlFeSi phases

As solutionised



Most of the Mg_2Si particles are dissolved

AA5754 FOR STRUCTURAL APPLICATIONS

- AA 5754 is moderate formability alloy used for the body structure of AIV vehicles
  - **Supplied in fully annealed soft condition for forming (O temper)**
  - **Strain hardens during stamping and forming (cold work)**
  - **No natural ageing**
  - **No hardening during paint bake cycle**





- **Example: Jaguar XJ (full aluminum)**
  - **Body structure: AA5754 (~ 3% Mg no SCC sensitization)**
  - **Hood, roof, deck lid, fenders, doors: AA 6111**

AA5182 FOR INNER PANELS

- AA5182 is a high formability alloy used for inner panels
  - **Examples:**
    - **BMW 5 and 6 hood inner**
    - **Jaguar XJ hood inner**



- 5xxx alloys are not suitable for OUTER panels: Lüders lines…

Hood inners



Door inner

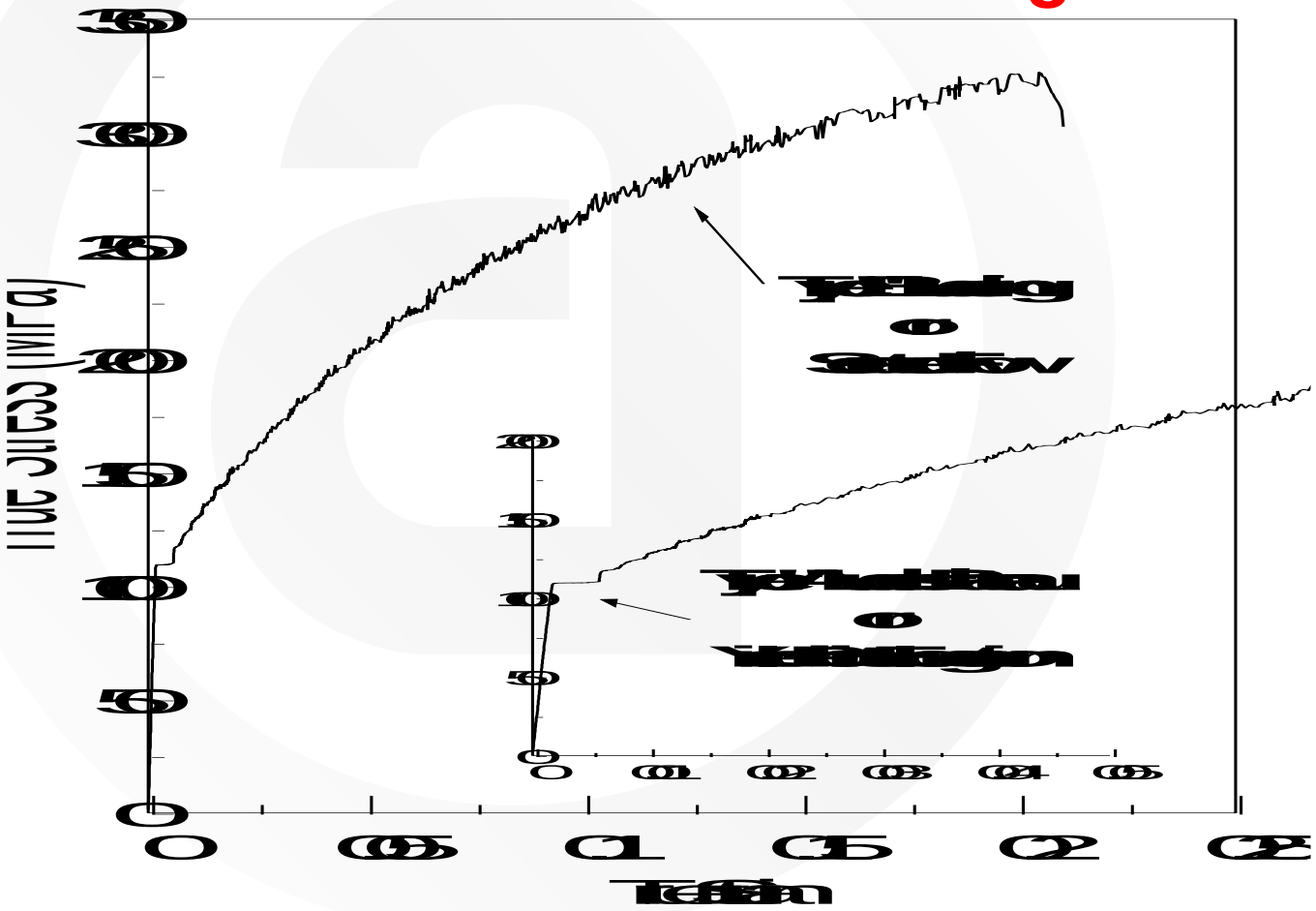


Deck-lid and tail-gate

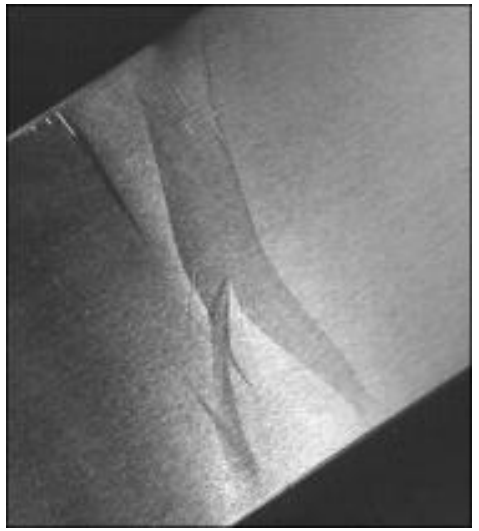


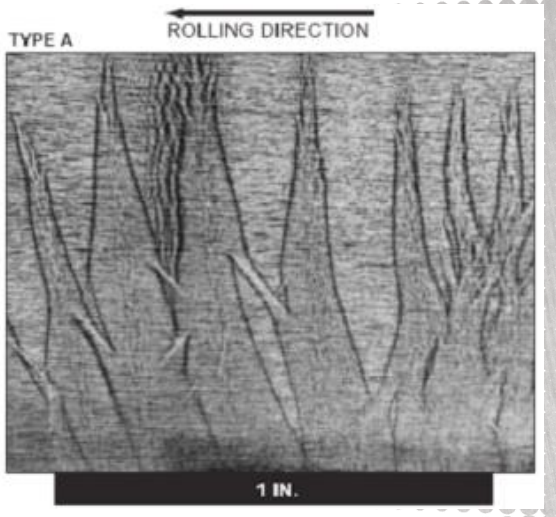
5XXX NOT SUITABLE FOR OUTER APPLICATIONS

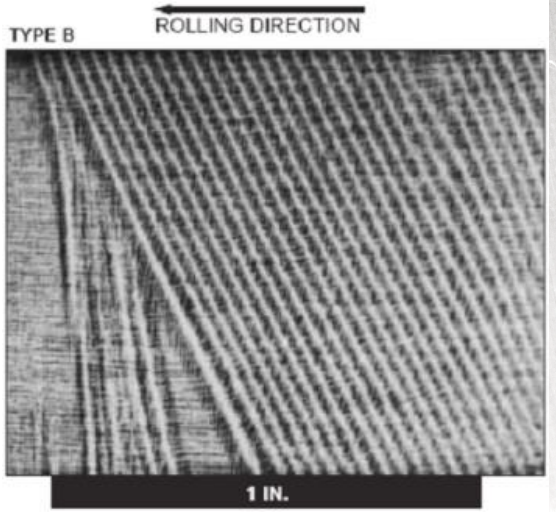
Stretcher strain markings



Stress strain curve for commercially produced 1.6 mm AA5182 O-temper







PLC video

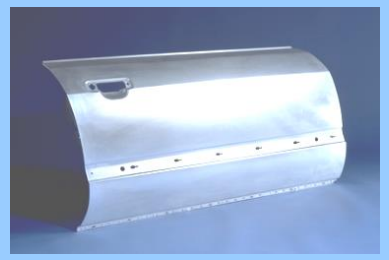
6XXX ALLOYS AUTOMOTIVE APPLICATIONS MAIN REQUIREMENTS

Applications

Requirements

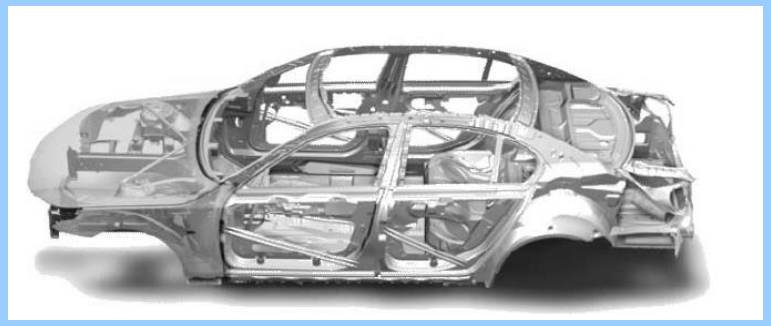
Attachments





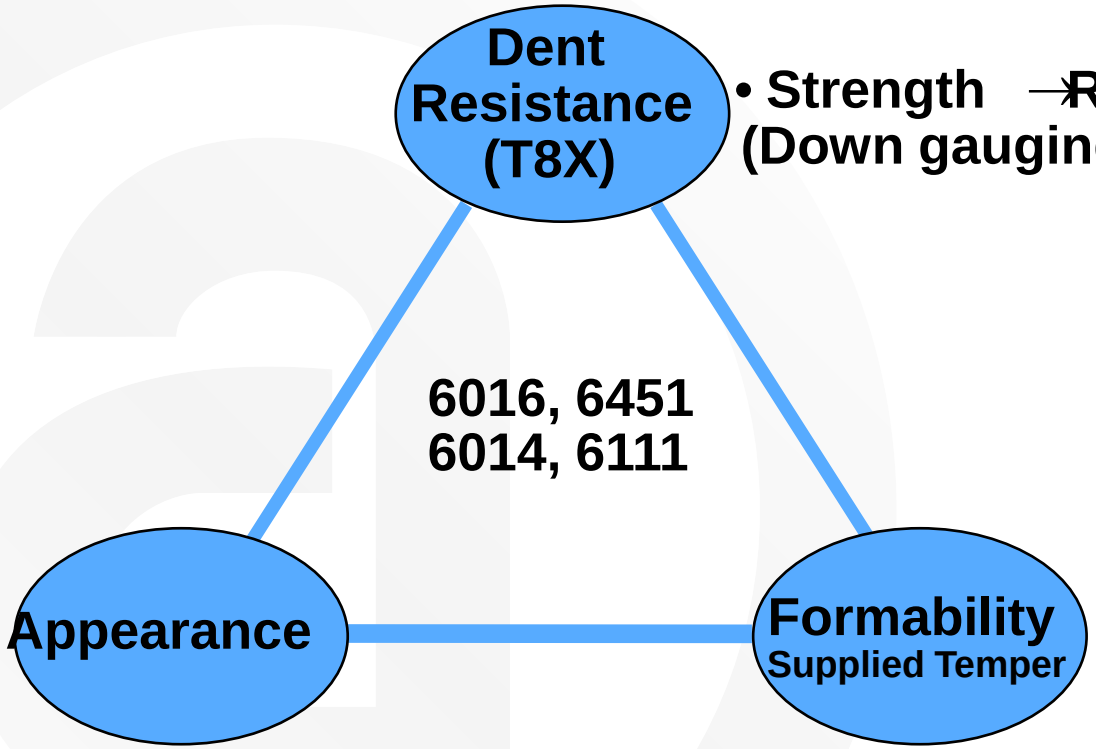

- Weight
- Formability
- Dent Resistance
- Surface Quality
- Paintability

BIW



- Weight
- Strength and Stiffness
- Crash-Performance
- Torsional Behaviour

6XXX PROPERTIES – OUTER PANELS



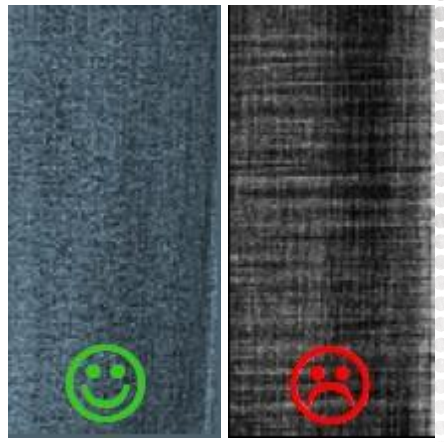
- Strength → Rapid ageing (Down gauging potential)

- **High surface quality**
- Corrosion resistance

- Hemming (r/t bends)
- Reduced springback
- Improved stretch

Roping/Ridging/Paint Brush Lines

To be controlled by processing (i.e. texture control)



6xxx Alloys – Artificial Ageing

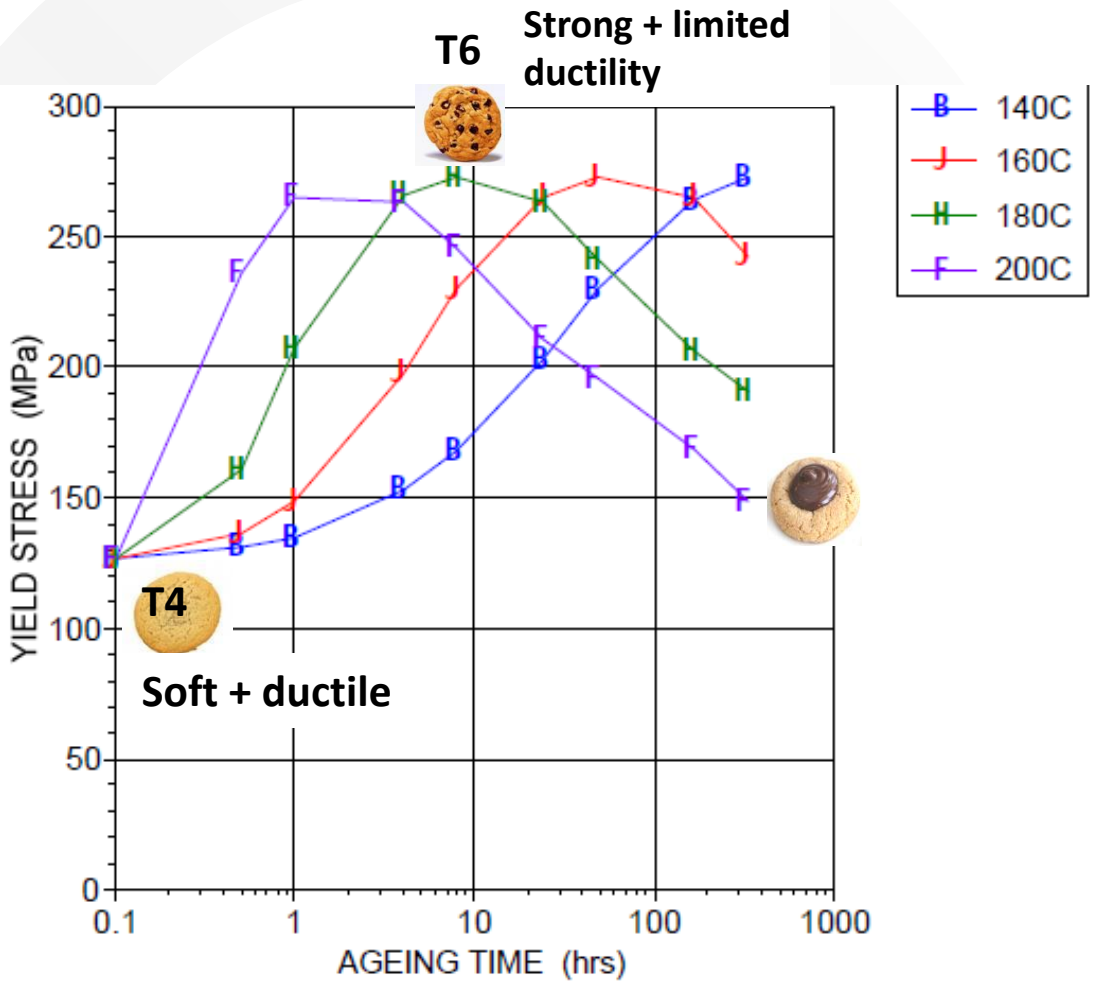
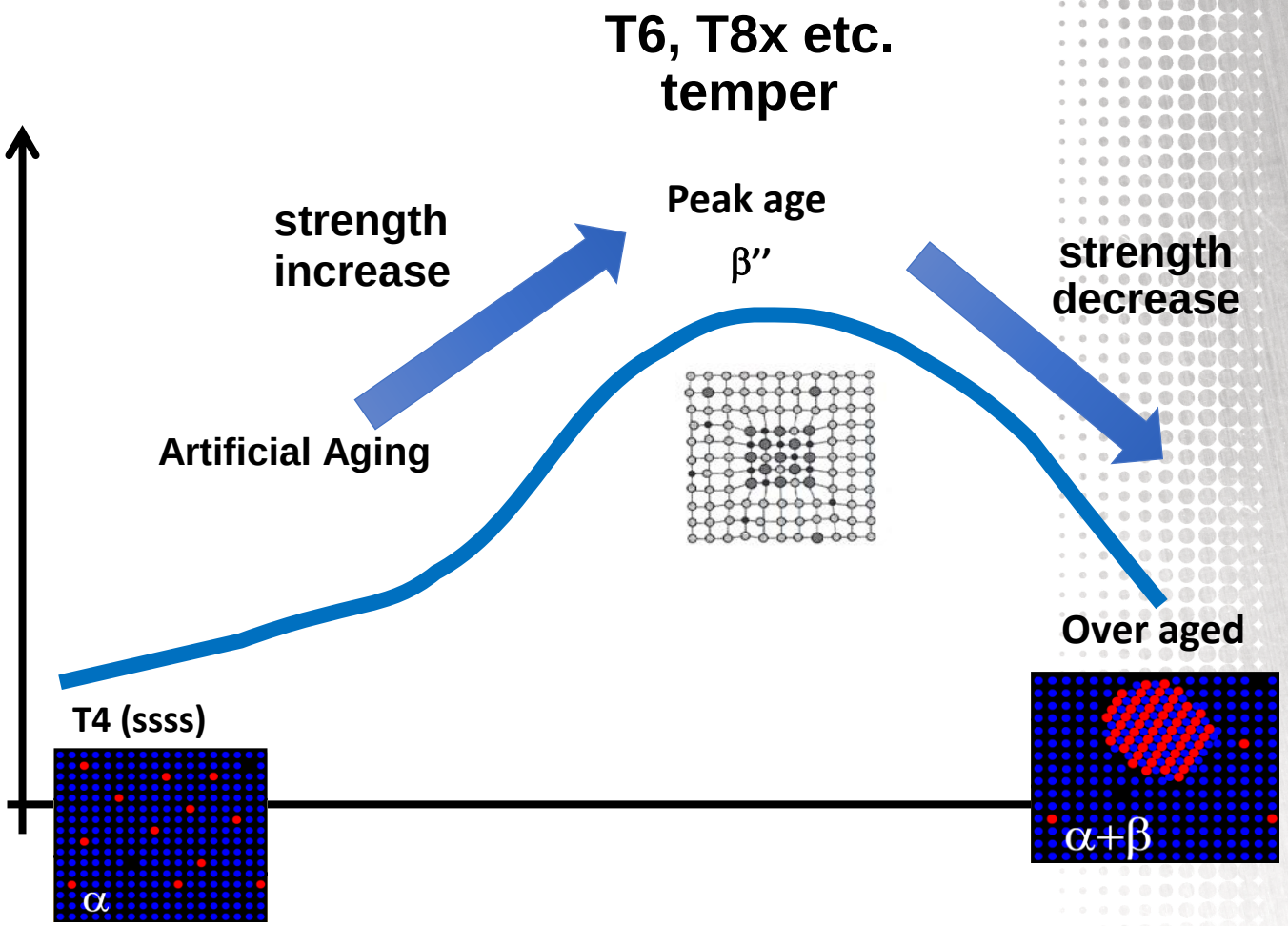


Figure 1. Ageing Curves for AA6016

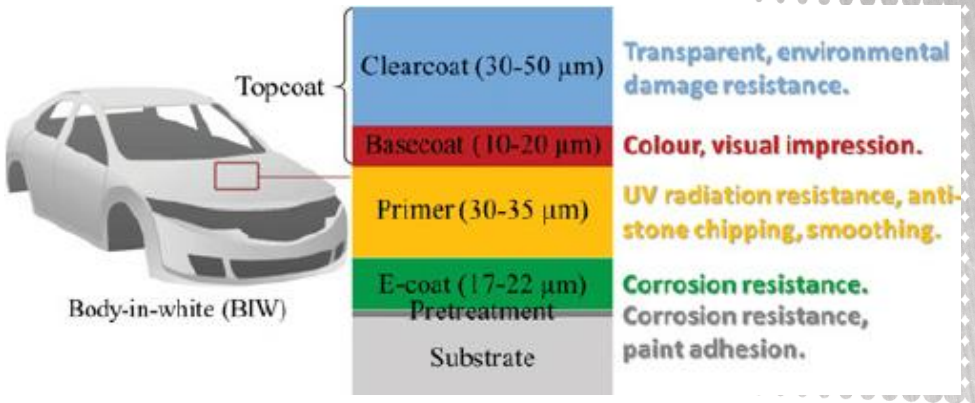


Artificial Aging- Automotive customer process

- Aluminum alloys can utilize paint bake in automotive process to achieve its desired properties in its final state.



- Typical automotive paint bake temperature ranges from 150-210C, allowing precipitate in aluminum alloys to form
- Peak aged condition is not always used. Overaged condition is sometimes considered to sacrifice strength for other attributes.





Paint bake



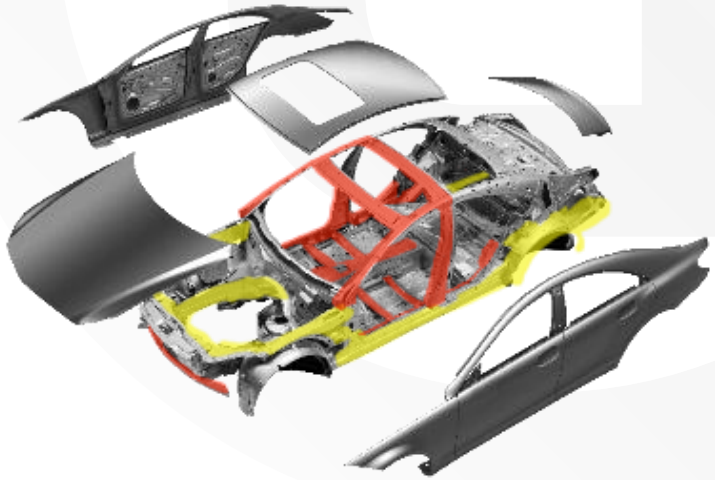
Final Properties
- **Strong**
- **Dent Resistant**



6XXX ALLOYS FOR STRENGTH DOMINATED APPLICATIONS

6HS2

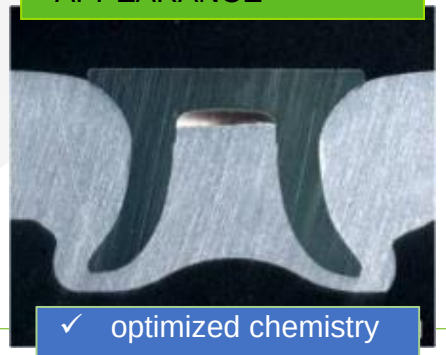
- In-service T8x (2%+185C 20min): 200-**250 MPa YS**
- Post-form Artificially Aged (PFAA) Condition: Min **290 MPa YS**
- PFAA material can be joined by Self-Piercing Rivets (SPRs), Resistance Spot Welding etc.
- Excellent Crash Performance



HS6xxx

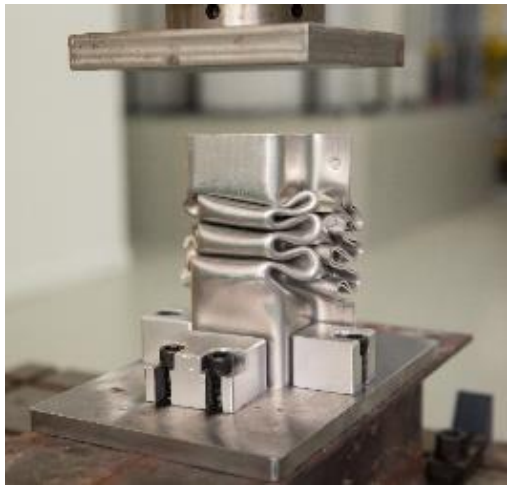


GOOD EXTERNAL AND INTERNAL APPEARANCE



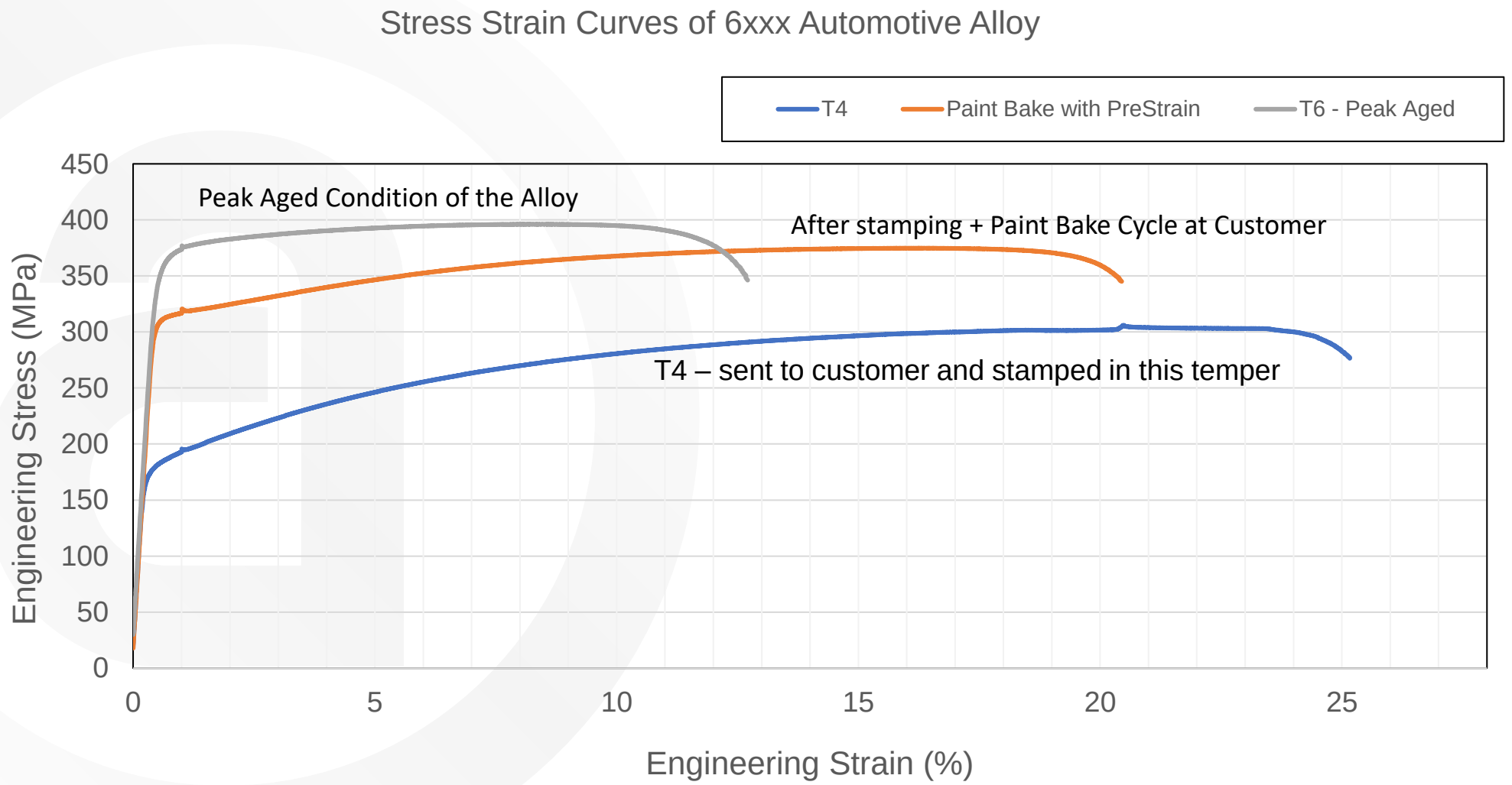
✓ optimized chemistry
✓ optimized processing

HS 6xxx



Successful folding with no tearing both in after paint bake and T6 tempers
Rivet ability issuperior
Good energy absorption

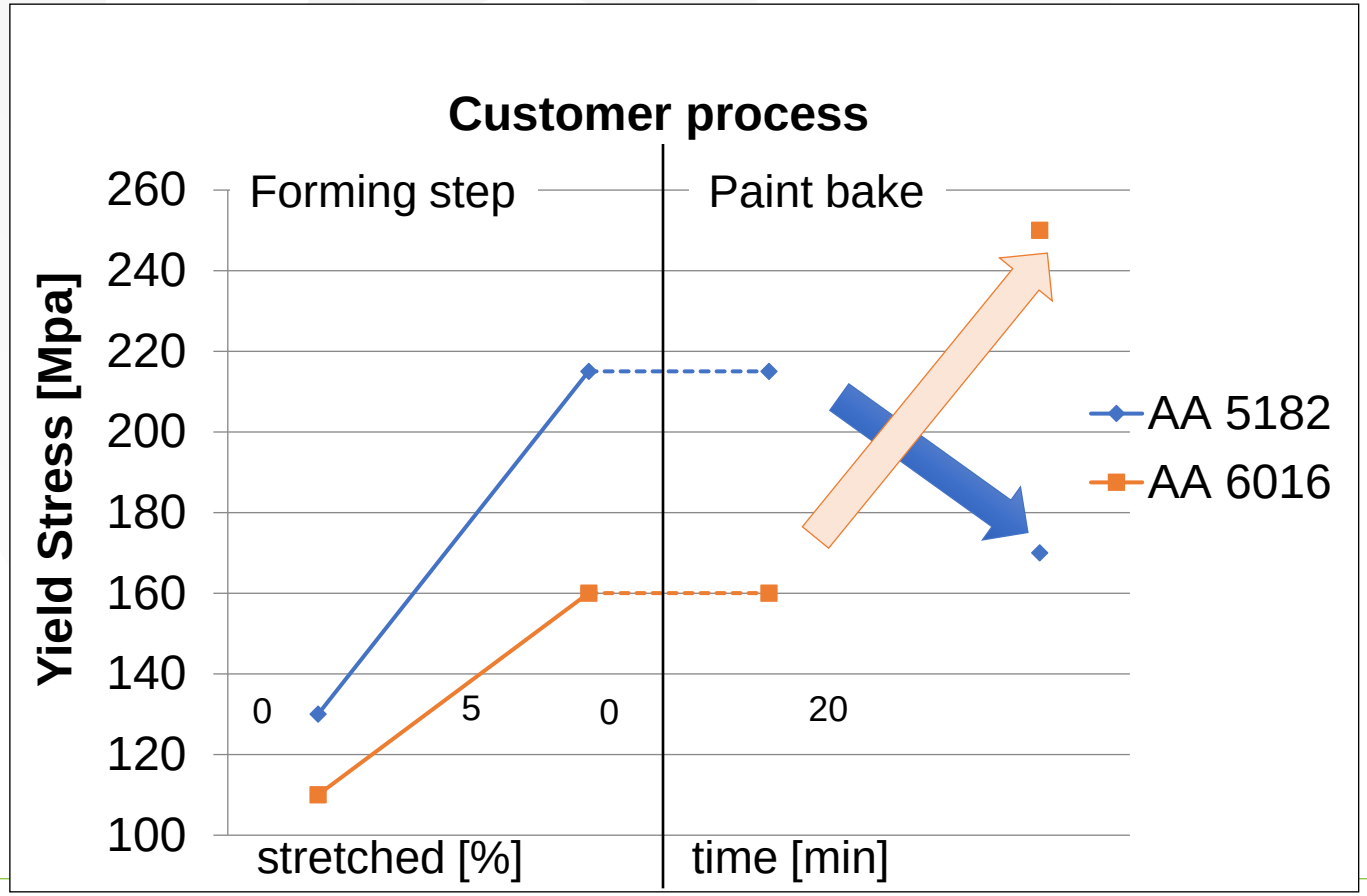
Leveraging OEM Paint Bake Cycles for In Service Strength



6XXX: INFLUENCE OF CUSTOMER PROCESS ON STRENGTH

Due to customer process 6xxx have a higher in service strength than 5xxx





Non age hardenable alloys

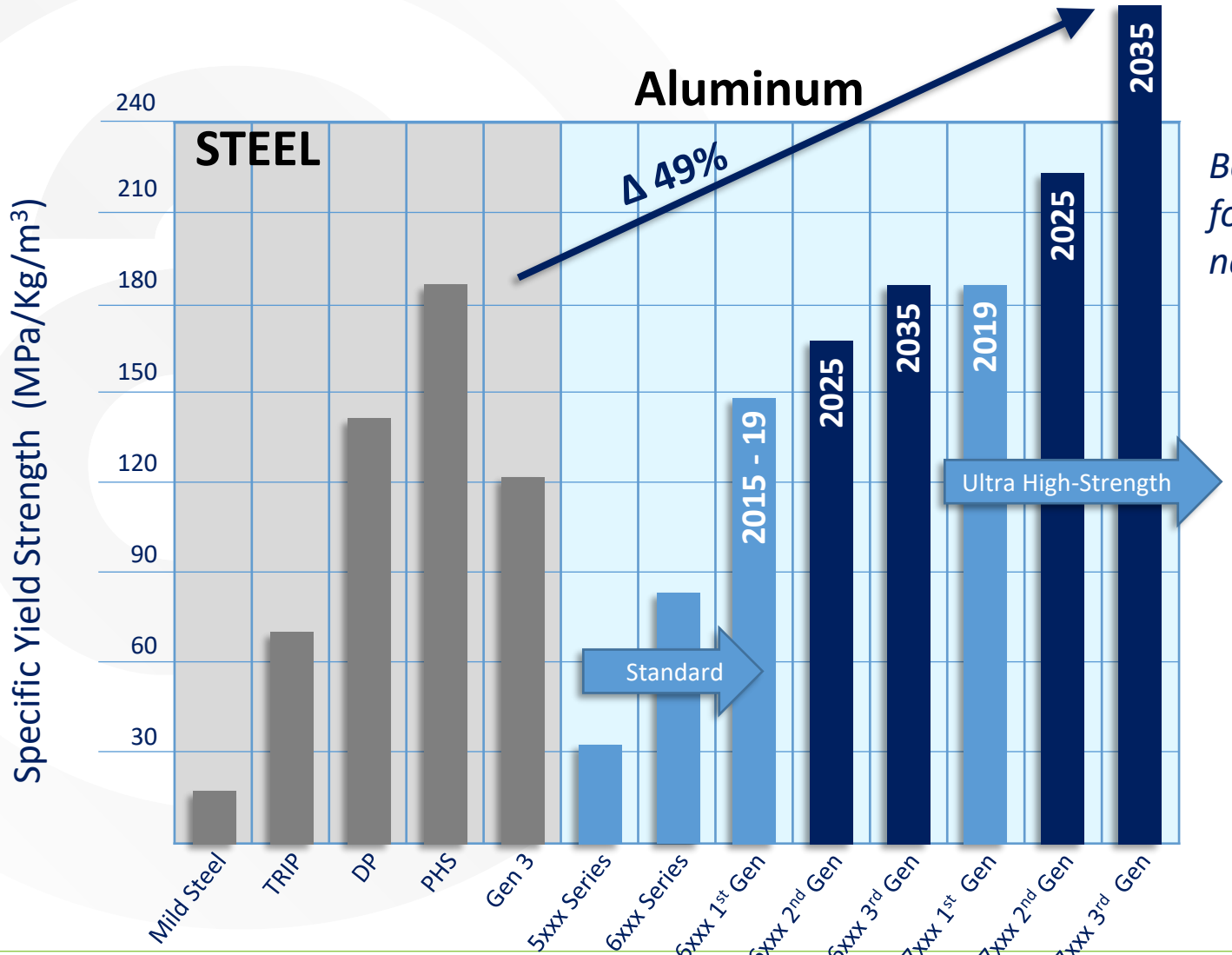
revert to original strength during paint bake process

Age hardenable alloys

gain strength during paint bake process

New developments

NEW ULTRA HIGH STRENGTH ALUMINUM (UHSAL) RISES TO THE CHALLENGE

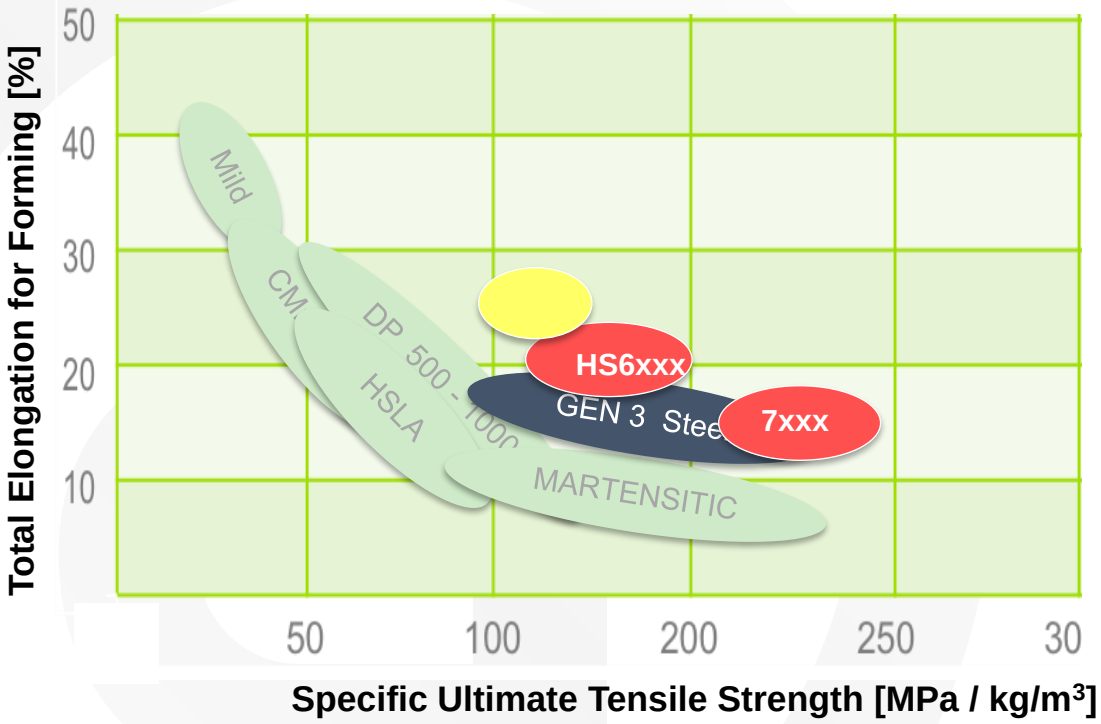


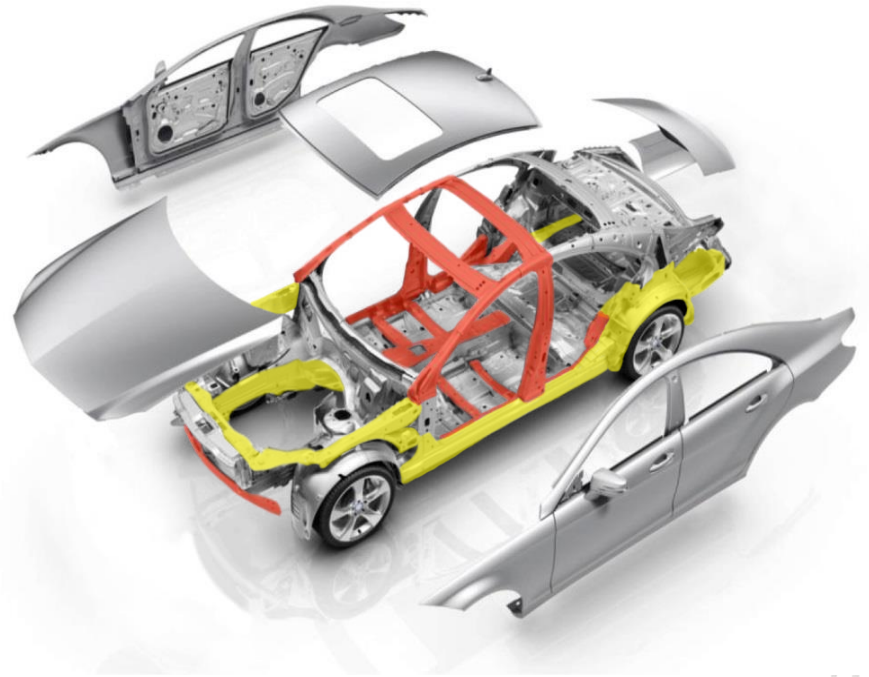
Both Sheet and Extrusion product forms rise to the challenge with new UHSAL grades.

Projected

Commercially Available

7XXX ALLOY DEVELOPMENT FOR HIGH STRENGTH





7XXX High Strength Alloy Targets

- Yield Strength in T6 or T7 condition of 500 MPa +
- Hot Form F Temper or Warm Form T6 or T7 Temper
- Gauge Range of 1 - 3.5 mm
- Auto Applicable (Not designed for Aerospace)



Future Challenges

RECYCLING ALUMINUM IS A KEY ENABLER FOR THE FUTURE

70-80%

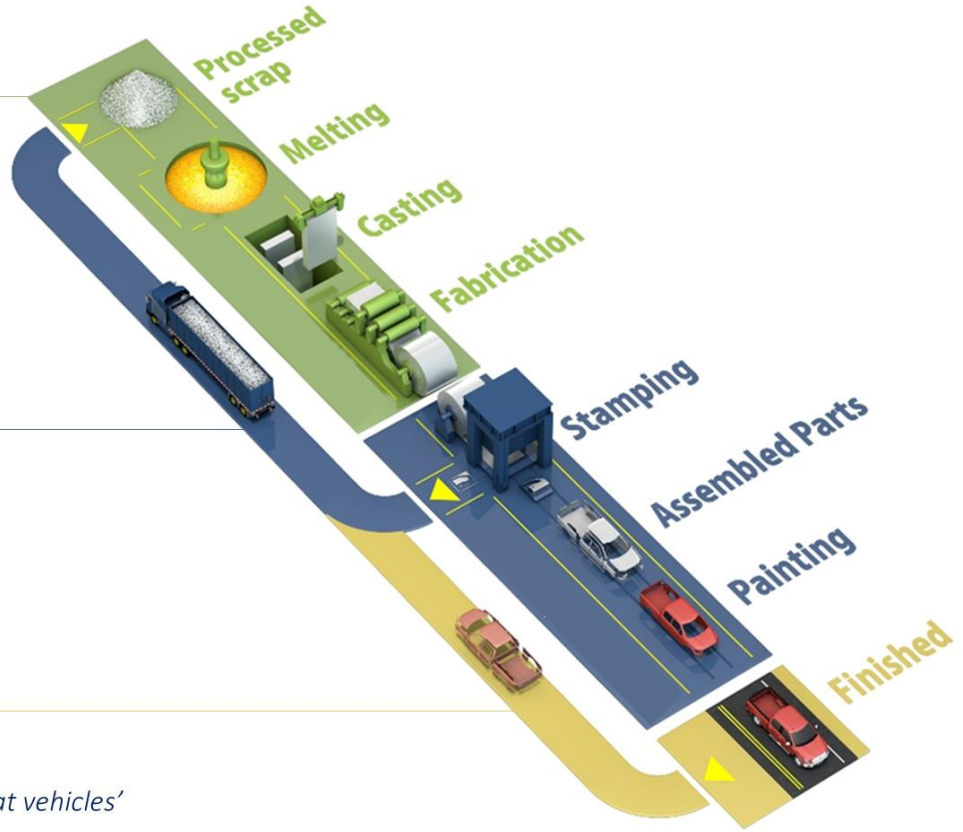
Recycle content for new ***high recycle content*** *grades*

100%

of production scrap can be returned to the same material in a ***closed loop***

>90%

of aluminum parts are recycled at vehicles' end of life[1]



1. Automotive Aluminum Recycling Rate Study, Sean Kelly, Diran Apelian, CR3 Center for Resources Recovery & Recycling

RECYCLING ALUMINUM IS A KEY ENABLER FOR THE FUTURE

The Challenge

Over 90% of Post-consumer EOL Al scrap (non-UBC) is currently down-cycled to the casting market.



Develop EOL scrap sorting technologies

Upcycle *auto EOL and press shop scrap into "new" wrought alloys*



KEY ENABLERS TO INCREASING ALUMINUM VALUE-IN-USE

Joining

- Resistance Spot Welding
- Remote Laser Welding
- Multi-Material Joining

Forming

- Hot Forming
- Roll Forming
- Textures & Lubes

Recycling

- Closed Loop
- Open Loop
- End of Life

Tailored Performance

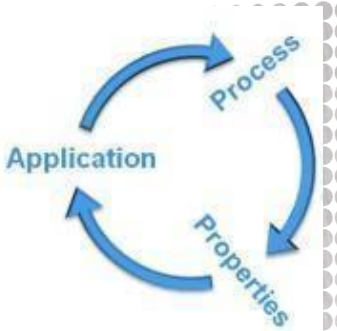
- Continuous Casting
- Tailor Rolling & Welded Blanks
- Optimized Extrusion Design
- Multi-alloy Sheet

20-40%

Value Improvement

ALUMINUM SHEET AUTOMOTIVE ALLOYS : KEY POINTS

- Drivers behind aluminium use in automotive applications
  - **Weight savings**
  - **Reduce fuel consumption (lower CO_2 emissions)**



added benefits... accelerates more quickly, provides better stability and response, and requires shorter stopping distances than heavier vehicles.

- 5xxx and 6xxx: main alloys for sheet automotive applications
- Development areas
  - Higher performance alloys
    - Strength/formability
  - Customer processing
    - Joining - welding, bonding, SPR etc. – multi-material architecture
  - In service needs
    - Crash worthiness, corrosion resistance
  - Cost competitive
    - Higher recycling content, continuous casting

Additional challenges

- Automotive is a global business
- Need to be a global supplier
- Global specifications

Questions?