



Introduction to Aluminum Extrusion

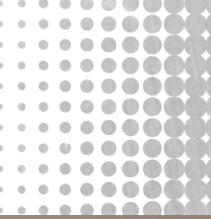
The Aluminum Transportation Group

Presenter

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What is Extrusion?

- A shaping process using pressure to force material through a die, producing a constant cross section that is long in relation to its width
 - Extrusion is a solid state process – melting does NOT occur
 - Aluminum billets (the starting stock) are preheated prior to extrusion
 - Metallurgical properties can be adjusted by adjusting the process parameters



Agenda

- Extrusion process
- Age versus unaged
- Extrusion alloys commonly used in automotive applications
- Extrusion alloy properties
 - Specialty alloys – crash performance, high strength
- Typical automotive applications for extrusions
- Guidelines for extrusion design
- Summary

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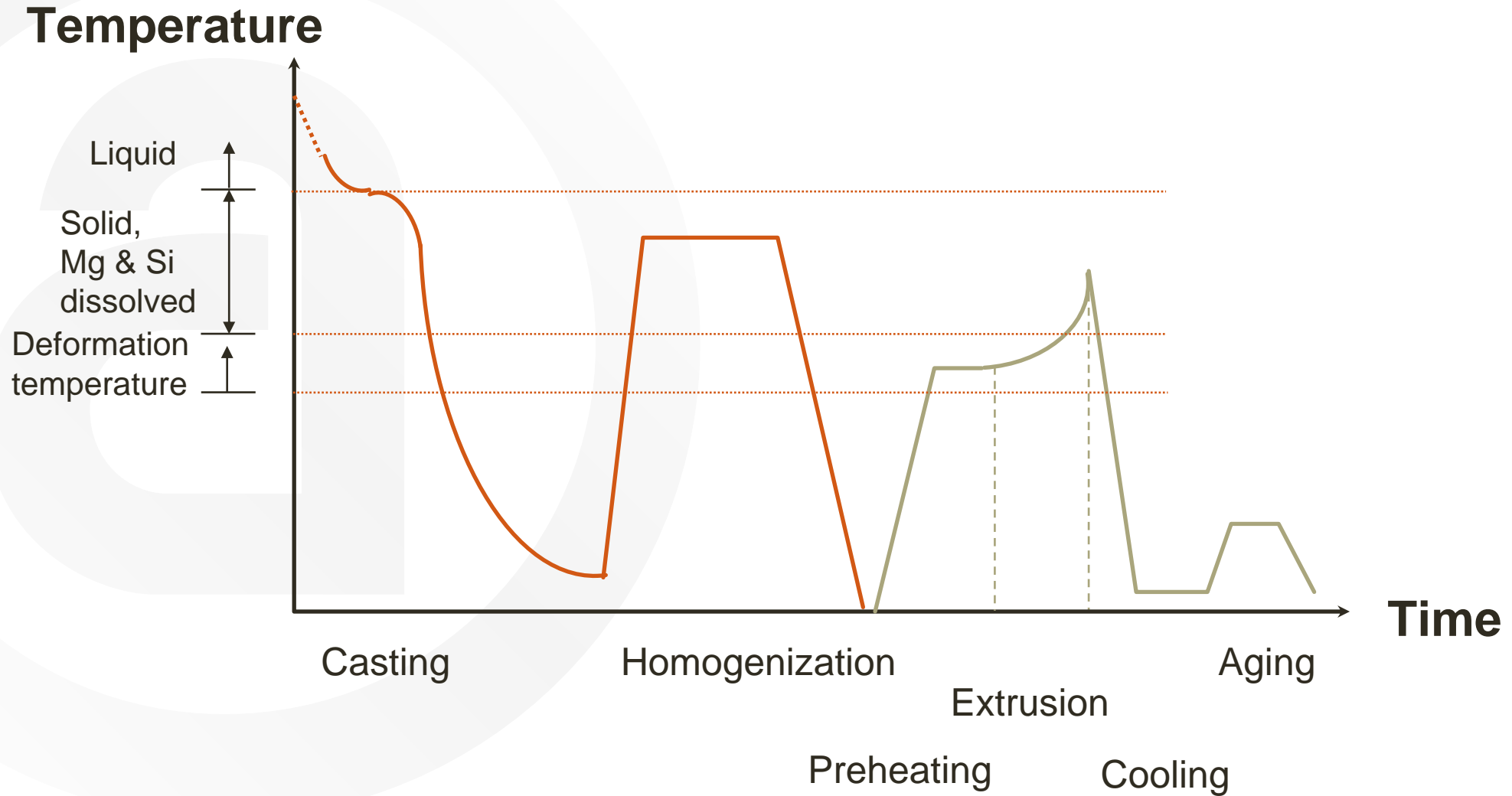


Process Description

1. Log casting
2. Homogenization
3. Preheating
4. Extrusion
5. Quenching
6. Stretching
7. Aging

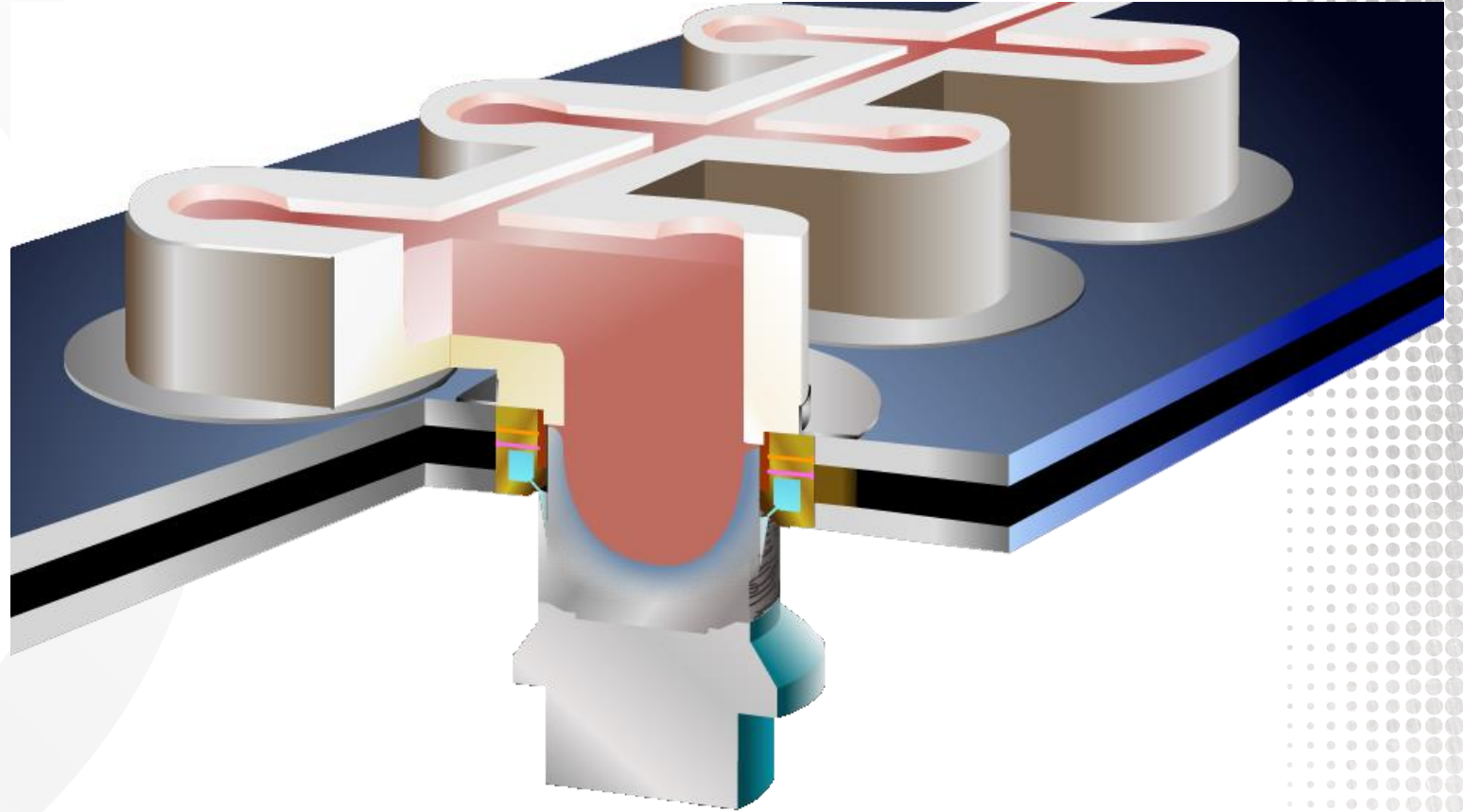


Press Quenching Thermal History



Log Casting

- Extrusion starting stock is generally cylindrical, hence “logs”
- Molten metal is a combination of prime alloy and recycled material
 - Up to 100% recycled
- Molten metal is treated to remove inclusions & hydrogen, then cast using the direct chill method

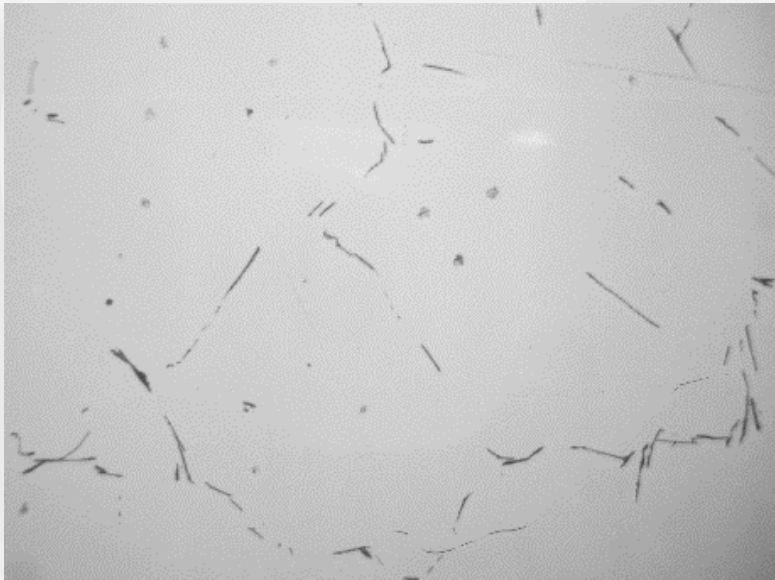


Finished Logs



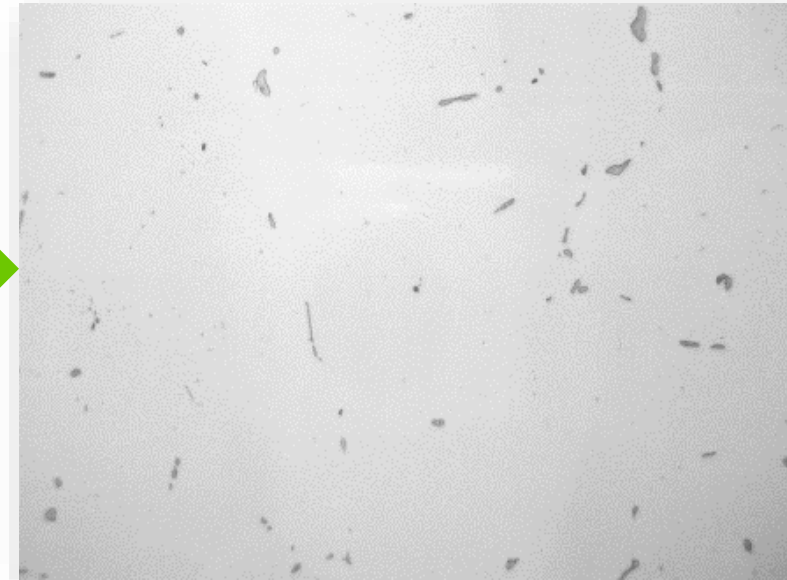
Homogenization

- DC casting involves rapid solidification, resulting in a nonuniform microstructure
 - This can lead to differences in key properties such as strength, ductility and grain structure
- Homogenization is a process transforming specific phases with time and high temperature



As-cast AA6063 Microstructure, 500x

Homogenization



Homogenized AA6063 Microstructure,
500x

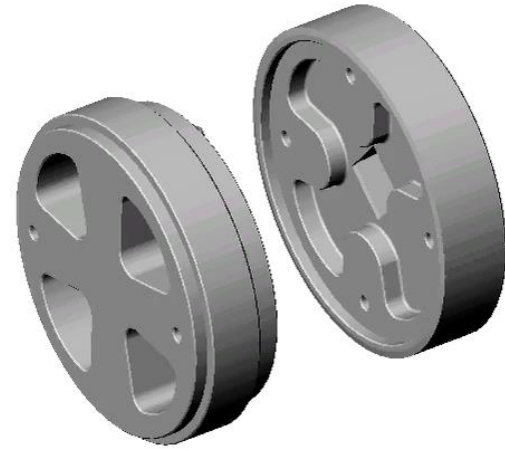
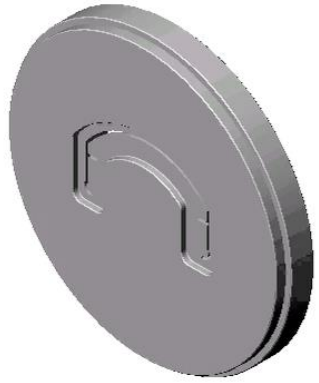
Images courtesy of Hydro
Extrusions

Preheating

- Extrusion presses load billets cut from logs
 - Billet length depends on equipment and also finished part – only extrude the lengths needed
- Prior to loading into the extrusion press, billets are preheated
 - Both gas and induction heaters are utilized

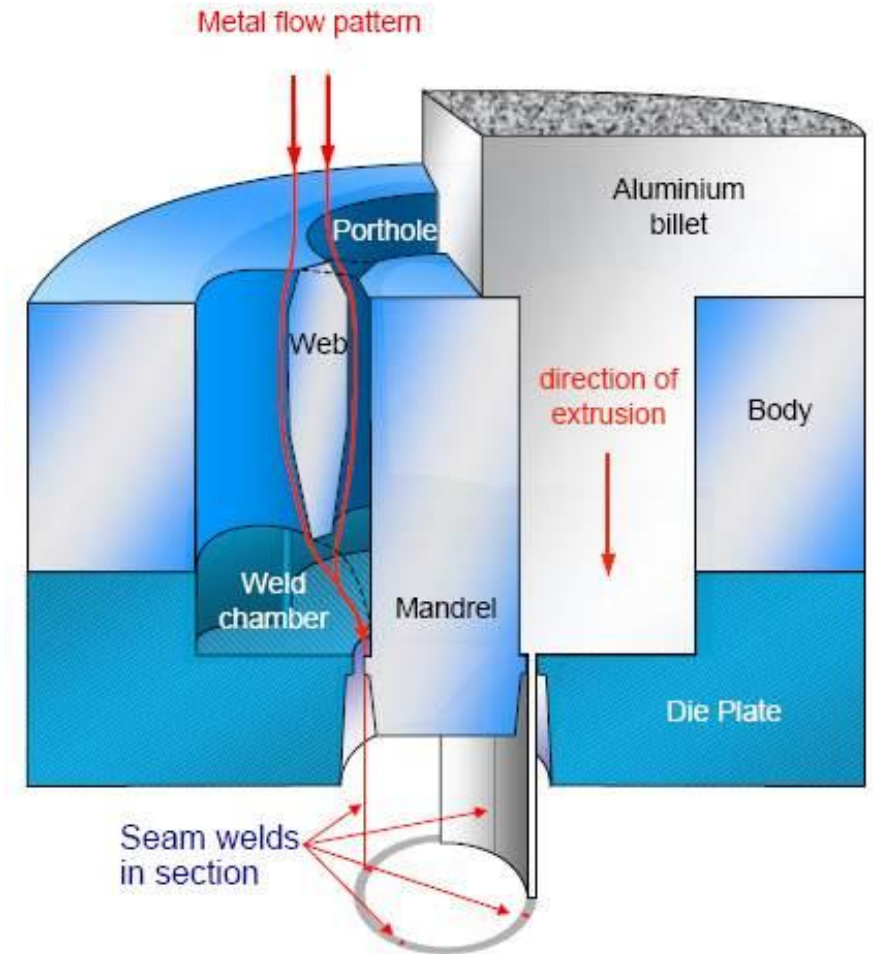


Dies



Structural Hollow Profiles

- Hollow profiles can be produced from solid billets known as *structural hollows*
- The billet “splits” inside the die and the flows rejoin around a mandrel, forming the hollow profile
 - Often called a seam weld, this is a solid state bond generated by temperature & pressure inside the die
- Multivoid hollows can be extruded with this method
- Good seam welds have the same strength as the bulk structure
- Grain structure may be different along a seam weld



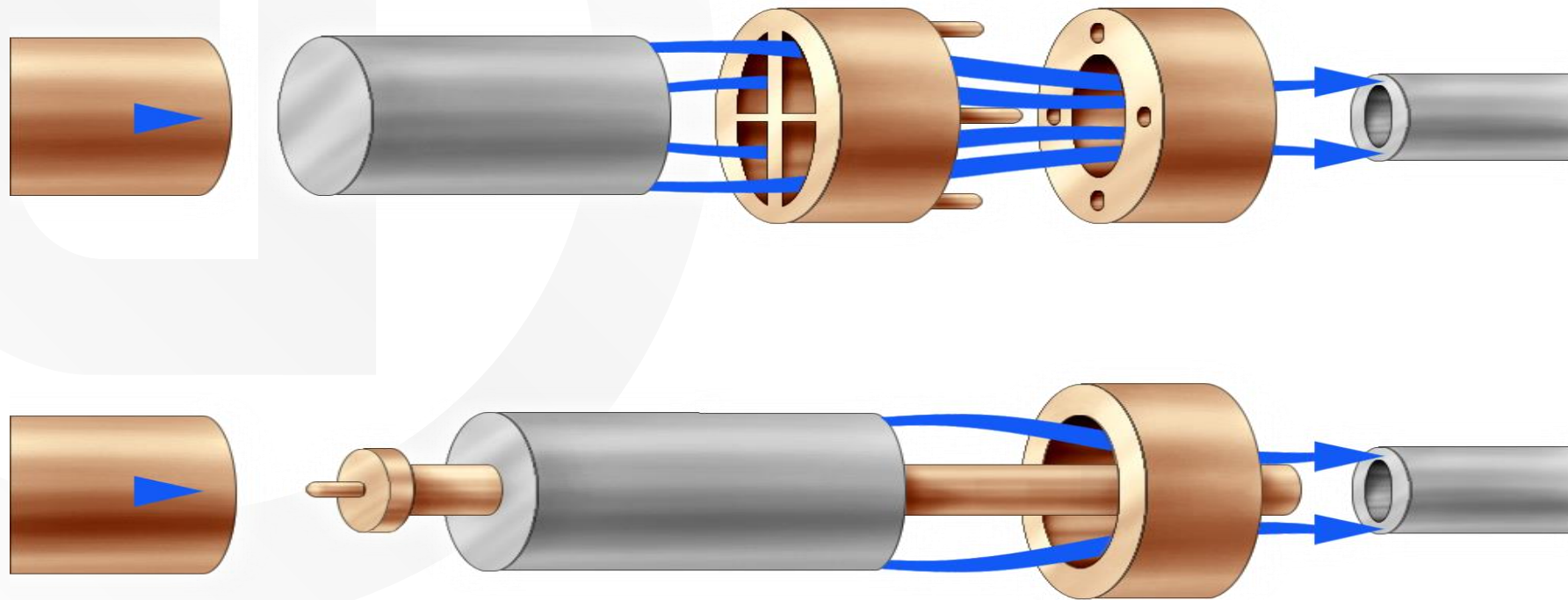
Structural Hollow Profiles



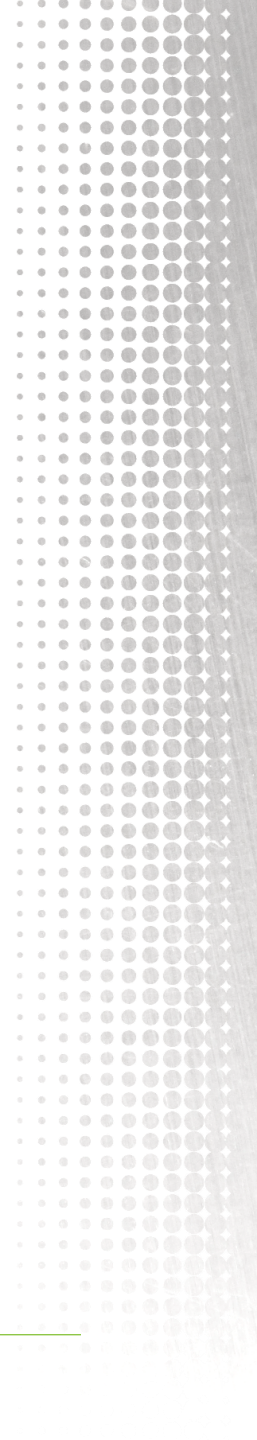
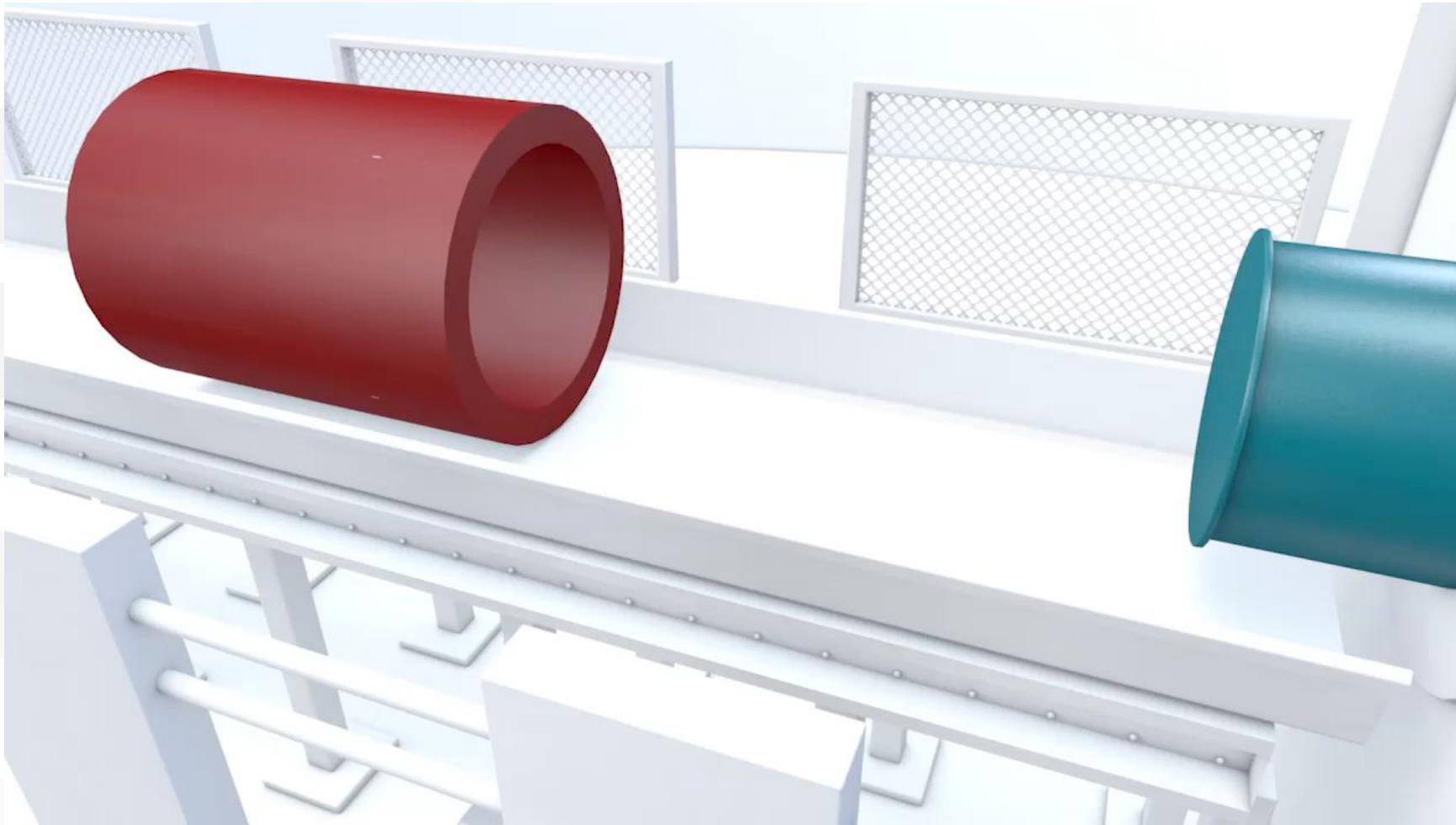
Östen J SAPA

Seamless Extrusion

- Single void hollows can also be produced as *seamless extrusions*
 - Most commonly round tubes, but other single void profiles are possible

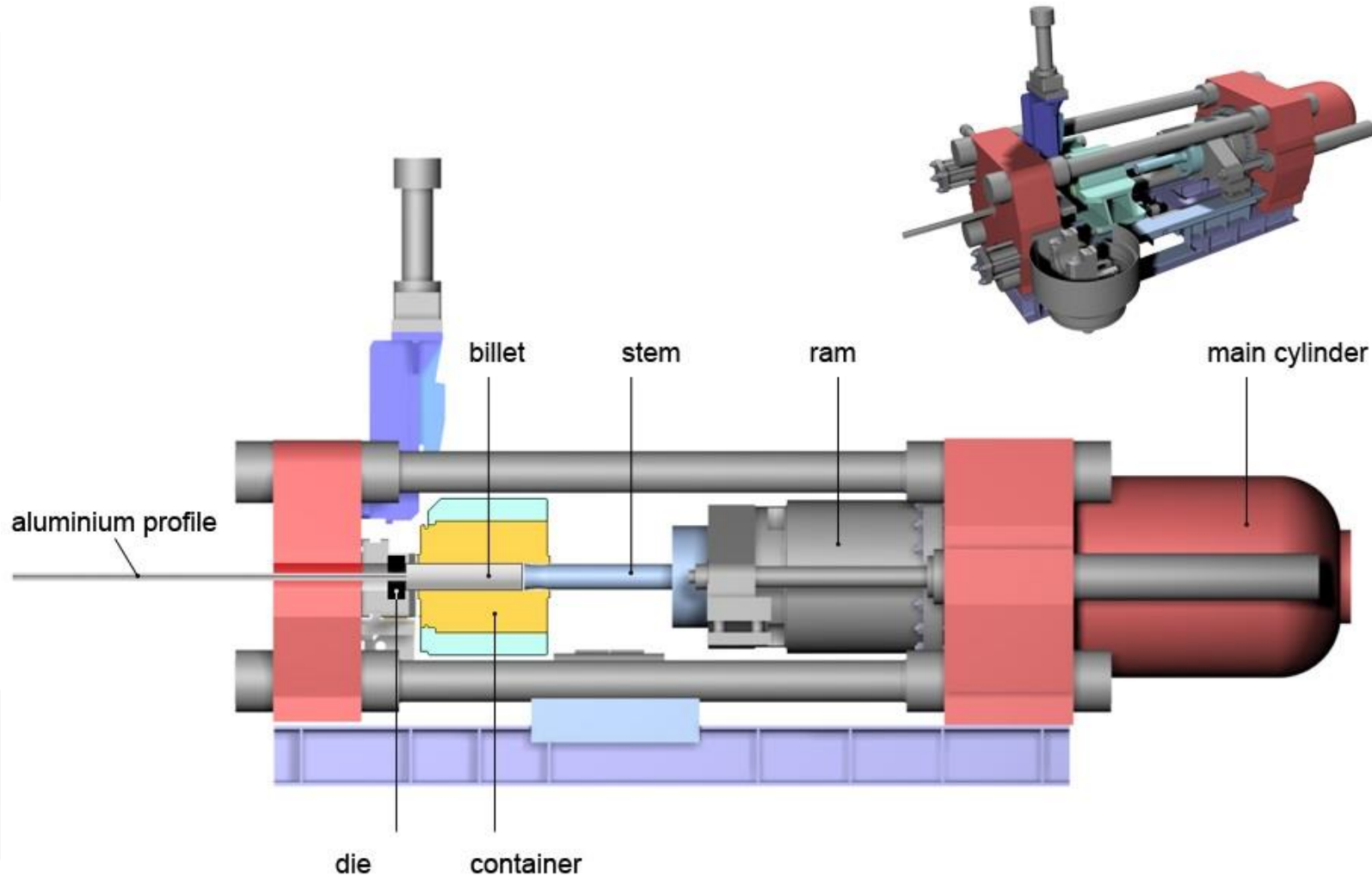


Seamless Extrusion Process



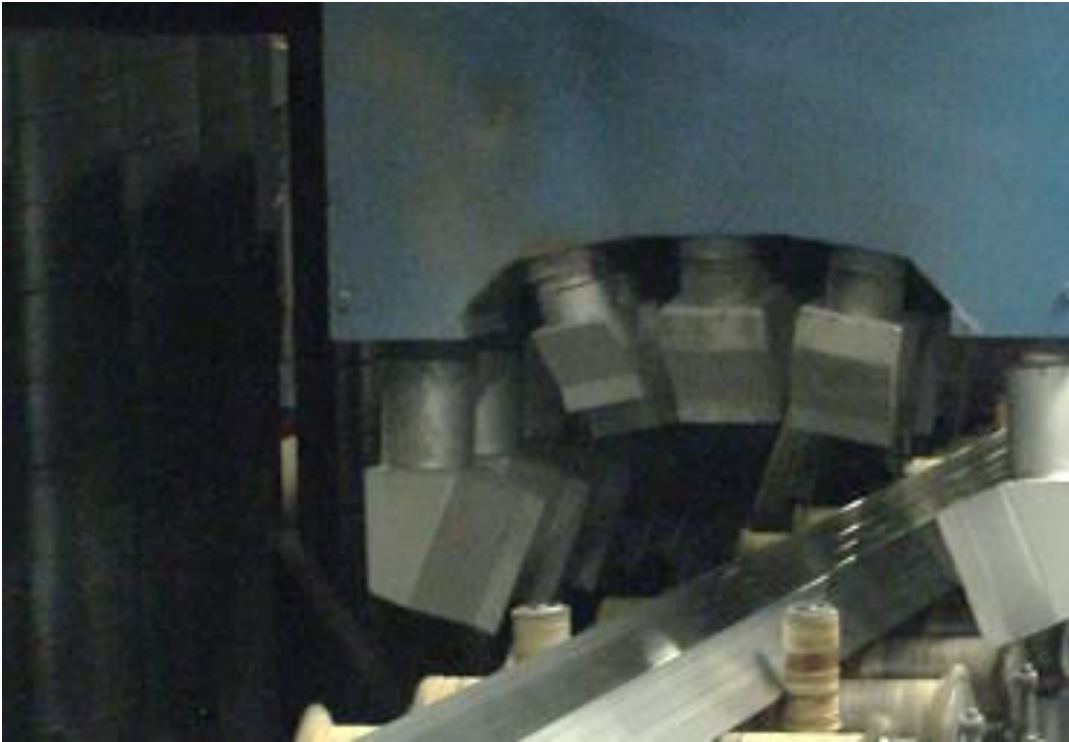
Extrusion

- The preheated billet is loaded into the extrusion press and pushed through the die, producing the desired profile
- Presses can range from 500t to 11,000t or more
- Billet diameters can range from <3" to >24"



Quenching

- The profile's exit temperature can range from 400° C to over 580° C (750° F to 1085° F)
- For handling, safety and metallurgical properties, profiles are quenched
 - For some alloys, heat treat can be done at the extrusion press as well (**press heat treatment**)
 - For other alloys, this requires an entirely separate process



Stretching

- Profiles are stretched for straightness and stress relief after quenching
 - Minimizes quench distortion and residual stresses
 - Typically 0.5% – 1.5% of total length

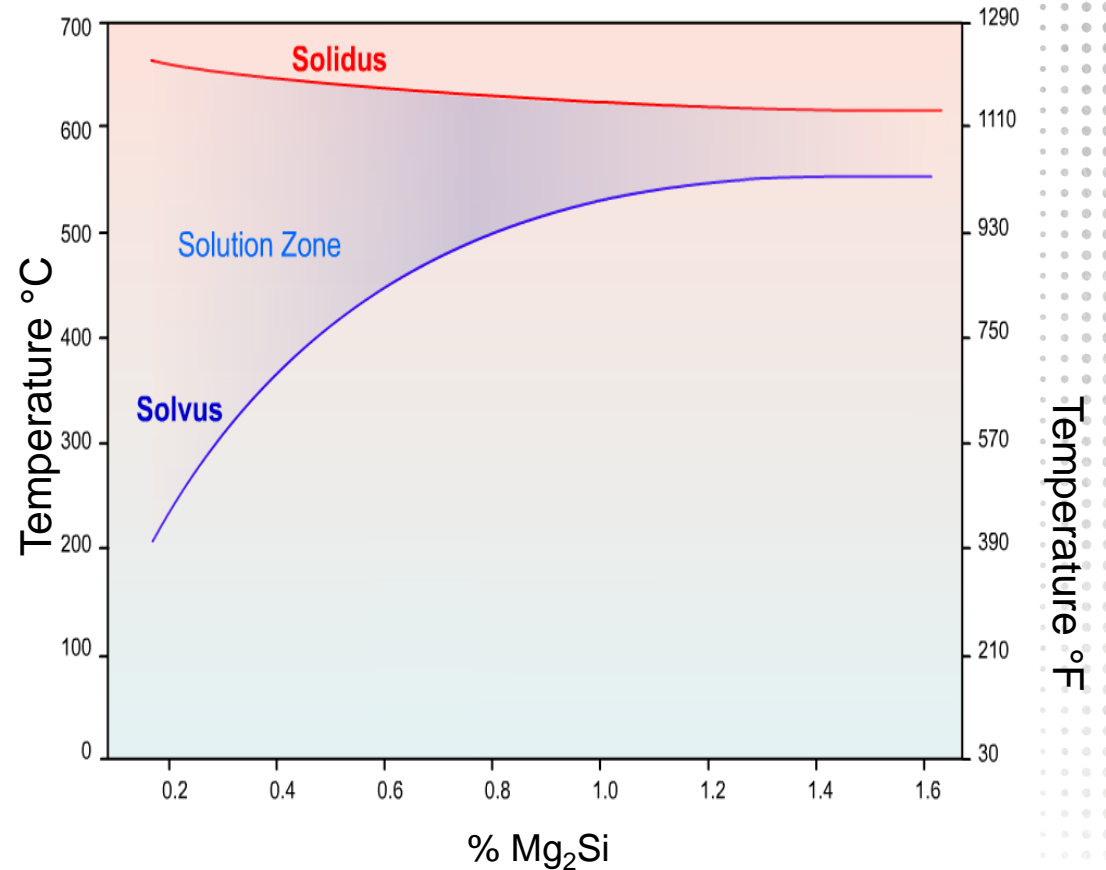


Extrusion Recovery

- The extrusion process is not 100% efficient – one pound of billet does not equal one pound of finished product
 - In the extrusion industry, the percent of good material is the recovery
- Typical recovery is 63% to 80%
 - This depends on the profile weight, cut length, quality requirements and equipment capabilities
- This information is often considered proprietary by the extruder, as it is linked to their process control
- Flexibility in cut length, alloy-temper and testing requirements may have a large impact on recovery
 - It never hurts to ask the extruder to quote “best length”

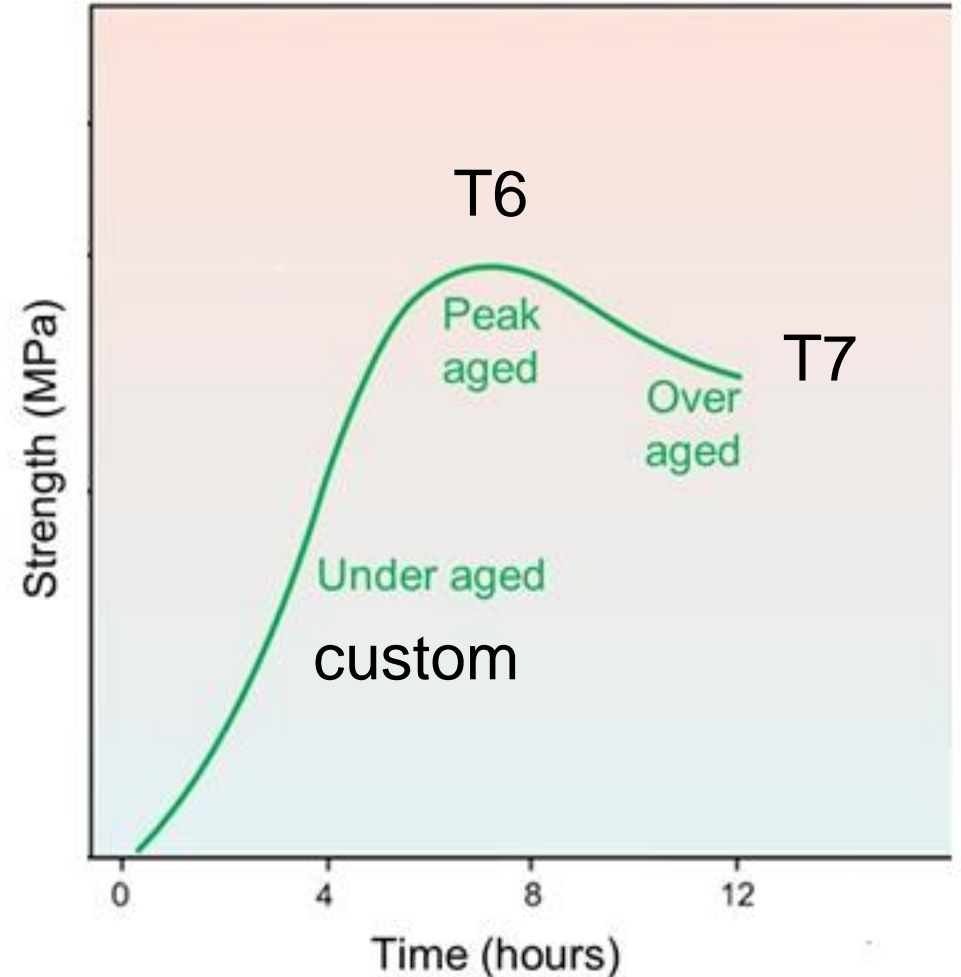
Aluminum Metallurgy

- Heat treatable aluminum alloys gain strength through precipitation heat treatment
- At high temperatures, aluminum dissolves more strengthening elements
 - Think sugar in hot vs cold water
 - Solid state process; nothing is liquid
- By rapidly quenching, strengthening elements can be locked in a metastable state
- This process can be a separate operation or in combination with the extrusion process
 - Equipment and alloy limitations will define which method is utilized



Aluminum Metallurgy

- The final properties can be tailored by controlling how strengthening elements come out of solution (precipitate) during aging
 - Properties that can be tweaked by aging include strength, ductility, conductivity and corrosion performance
- Specific properties can often be achieved through different methods of aging – understanding the end use helps to ensure the correct method is selected



Aging

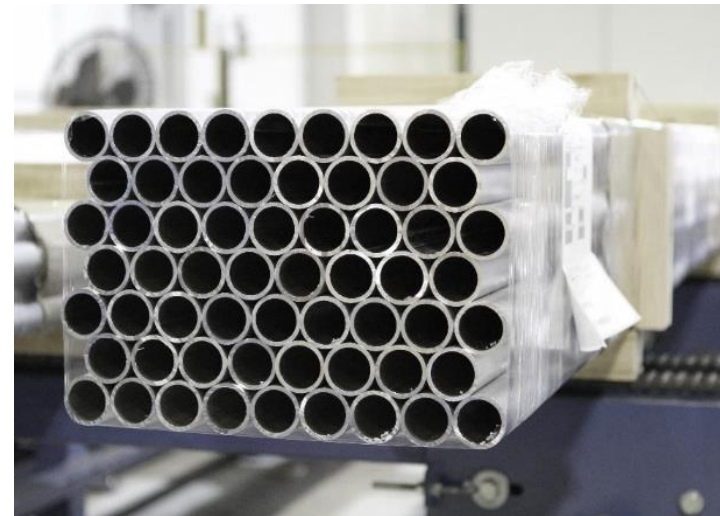
Artificial Aging

- Occurs in ovens or furnaces
- Higher temperatures shorten the required time
- Typical cycles 2-10 hours at 350 – 400 F



Natural Aging (Unaged)

- Occurs at or close to room temperature
- Properties will change with time
- Parts are more formable and often bent or formed, followed by artificially aging



Aged Vs. Unaged

- After profiles are solution heat treated, mechanical properties are not stable
 - Strength, corrosion behavior and other properties will change with time
 - This can have a large impact on fabrication if the supply chain is not well controlled
- Unaged profiles have greater ductility and lower strength, making them more suitable for forming/bending
- Unaged tempers can be aged to meet aged requirements after forming
 - This assumes suitable and well controlled thermal processes
- A hybrid option is stabilization – a low temperature aging practice that has minimal impact on formability and halts natural aging
 - This means a stabilized profile is stable and properties will not change with time

Typical Automotive Extrusion Alloys

Extrusion alloys used in automotive applications depend on part specific requirements

Non-Heat Treatable Alloys	Heat Treatable Alloys
1xxx – Electrical applications	2xxx – Not common
3xxx – Heat exchangers, fluid transfer	6xxx – BIW, wheels, subframes, crash management, trim
4xxx – ABS blocks	7xxx (low-Cu) – BIW, crash management (less common)
5xxx – Not common	7xxx (high-Cu) – not common

Typical Automotive Extrusion 6xxx Alloys

- Heat treatable 6xxx alloys are the most common extrusion alloys
 - Wide range of properties available
 - UTS from <100 MPa to >310 MPa with standard alloys
 - Extruder specific alloys can approach 385 Mpa UTS
- Most alloys are covered by ASTM B221

Alloy	Composition (weight %)					Mechanical Strength					
	Si	Fe	Cu	Zn	Mg	Yield (MPa)		UTS (MPa)		Elongation(%)	
						T4	T6/T5	T4	T6/T5	T4	T6
6060	0.30-0.6	0.10 -0.30	0.10 max	0.15 max	0.35-0.60		150		190	14	8
6063	0.20-0.6	0.35 max	0.10 max	0.10 max	0.45-0.9	65	170	130	215	14	8
6005A	0.50-0.9	0.35 max	0.30 max	0.30 max	0.40-0.7	90	225	180	270	15	8
6061	0.4-0.8	0.7 max	0.15-0.40	0.25 max	0.8-1.2	110	240	180	260	14	10
6082	0.7-1.3	0.50 max	0.10 max	0.2 max	0.6-1.2	110	260	205	310	14	10

6060/6063 Alloy

- **Advantages**

- Moderate strength
- Good extrudability allowing complex profiles
- Excellent corrosion resistance
- Very good to excellent anodize & surface appearance
- Good formability and energy absorption in the overaged condition

- **Considerations**

- Lower strength than 6005A, 6061, and 6082



Images courtesy of
THULE

6061 Alloy

- **Advantages**

- Good strength
- Good corrosion resistance
- Better toughness than 6005A
- Good weld performance
- Can be anodized

- **Considerations**

- Surface not as good as 6005A or 6063
- May need specific grain size control for anodizing



Images courtesy of Aluminum Precision Products

6005A Alloy

- **Advantages**
 - Good strength (same as 6061)
 - Excellent corrosion resistance
 - Better extrudability than 6061
- **Considerations**
 - Less extrudable than 6063



Images courtesy of 80/20
Inc.

6082 Alloy

- **Advantages**

- Good to excellent strength (can be greater than 6061)
- High toughness
- Good fatigue properties
- Can be anodized

- **Considerations**

- More expensive than 6063, 6061 and 6005A
- Less extrudable than 6061
- Dimensional issues increase with profile thickness



Images courtesy of Constellium N.V.

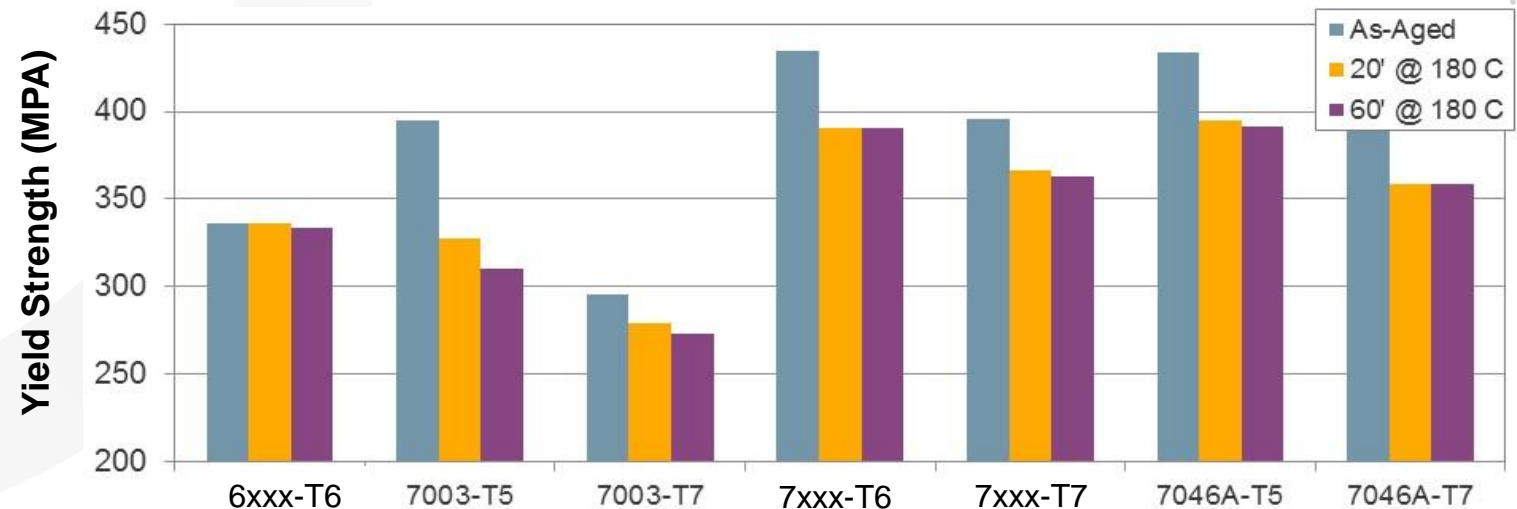
Typical Automotive Extrusion 7xxx Alloys

- Low Cu-7xxx alloys that do not require separate furnace heat treating
- Lower quench sensitivity, allowing for better dimensional control
- Limited number of suppliers
- Higher risk of stress corrosion cracking and require longer age cycles compared to 6xxx
- The strength loss after paint bake is greater for most 7xxx alloys than 6xxx
- Potential scrap segregation issues during fabrication and at EOL

Alloy	Composition (weight %)					Typical Mechanical Strength					
	Si	Fe	Cu	Zn	Mg	Yield (MPa)		UTS (MPa)		Elongation(%)	
						T4	T6/T5	T4	T6/T5	T4	T6
7003	0.30 max	0.35 max	0.20 max	5.0-6.5	0.50-1.0	n/a	324	n/a	375	n/a	16
7108A	0.20 max	0.30 max	0.05 max	4.8-5.8	0.7-1.5	n/a	360	n/a	400	n/a	8
7129	0.15 max	0.30 max	0.50-0.9	4.2-5.2	1.3-2.0	n/a	379	n/a	427	n/a	15

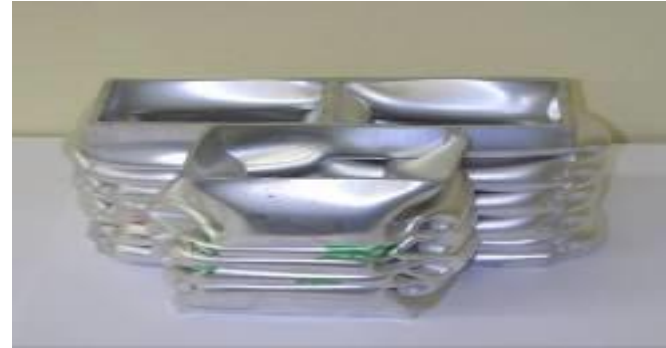
Potential 7xxx Issues

- Stress corrosion cracking
 - Accelerated testing used to quantify
 - Can be minimized by overaging, the trade off being lower strength (T7 vs T5/6)
- Accelerated aging kinetics
 - Greater loss of strength during paint bake
 - Preventable by not putting 7xxx extrusions through paint bake cycles



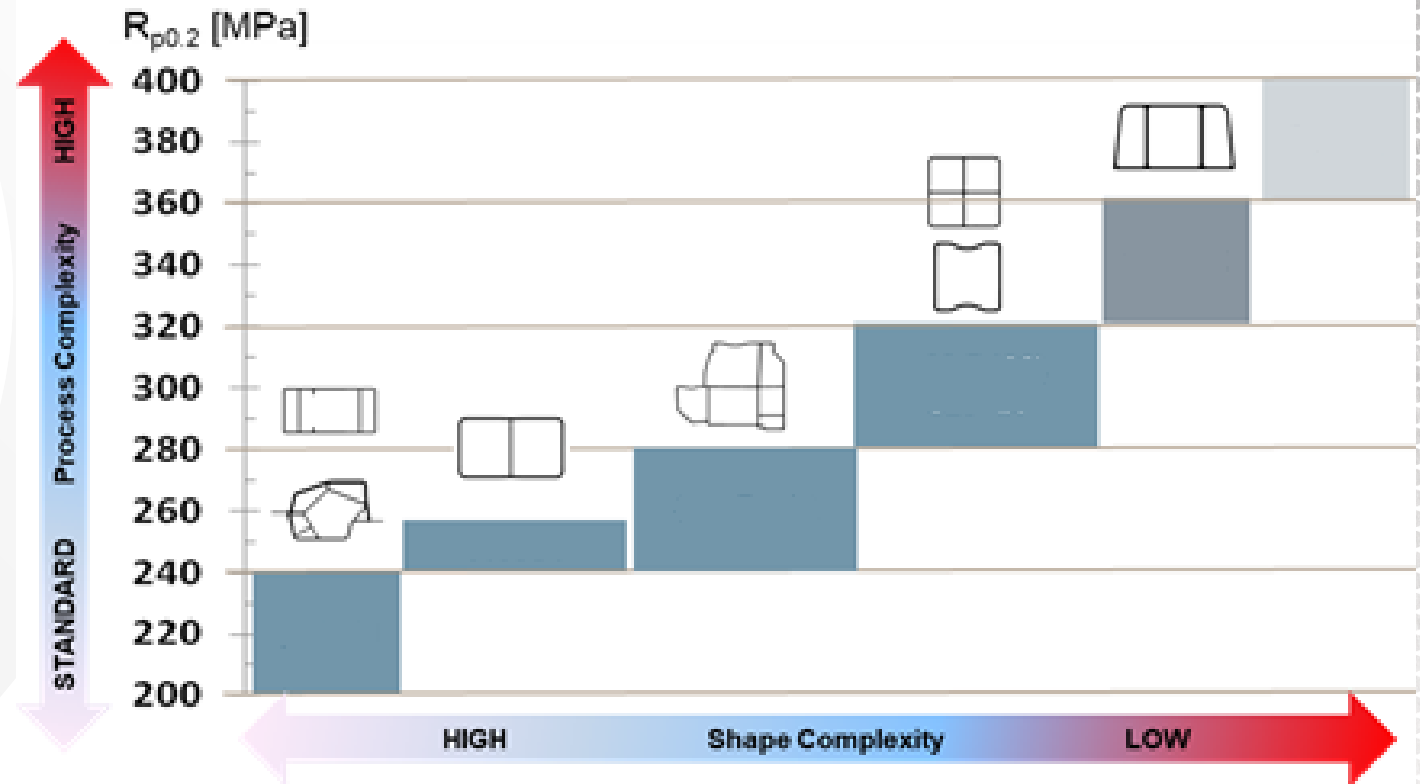
Crush Alloys

- Much more ductile than standard 6xxx alloys
- Many crush alloys are proprietary to the extruder or billet supplier and patent protected
- Options available in a wide range of strength and energy absorption ranges



Crush Alloy Portfolio

- Extruders have developed a variety of alloys for different applications
- Higher strength generally requires less complex profiles



Ductility Measures

- Elongation is NOT a good measure of ductility
- Better options include:
 - Reduction in area
 - True fracture strain
 - Bend testing
 - Visual grading
 - Energy Absorption during crush test

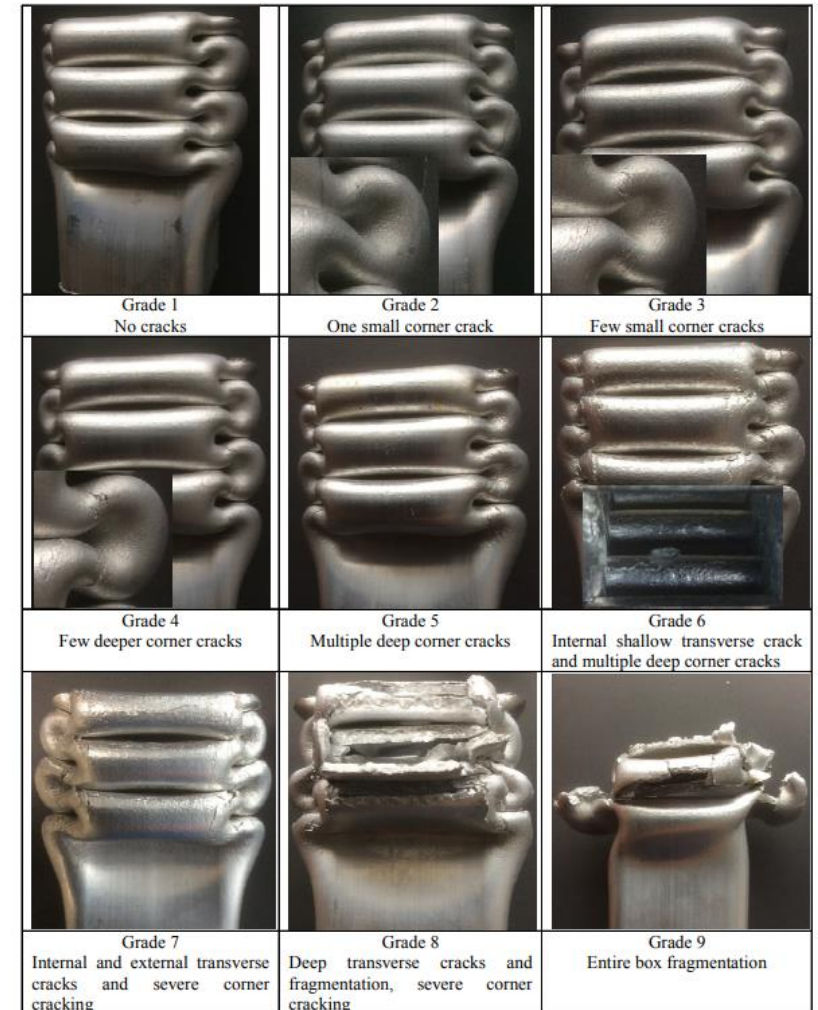


Figure 3. Crush grading system.

Source: "Extrusions for Automotive Crash Applications" Parson, et al.

Crush Alloy Testing

- 2-void profile
- 200 Mpa YS
 - “CA20”

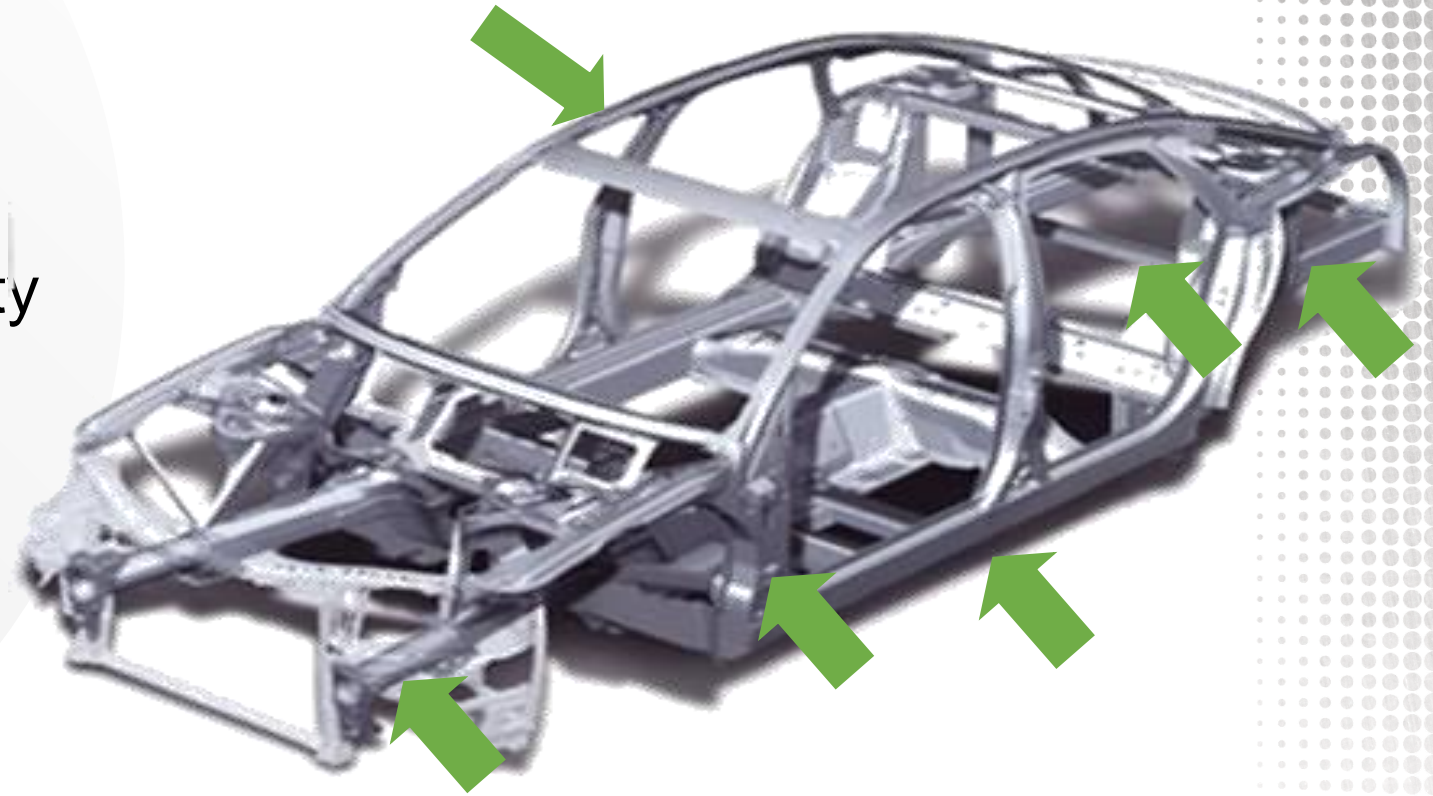


- 3-void profile
- 240 Mpa YS
 - “CA24”



Crush Alloy Applications

- Crash boxes front and rear
- Side impact protection
- Door beams
- Cantrails / roof rails
- Parts that require high ductility for forming



High Strength Alloys

- Common alloys have minimum yield strengths in the 270 – 300 MPa range
 - 6061 – T6 “elevated” ~275 MPa
 - 6082 – T6 “elevated” ~290 - 310 MPa
- Most extruders have proprietary solutions exceeding 340 MPa
- Similar to crash alloys, they are “grouped” in ~20 MPa buckets
 - 320 Mpa, 340 MPa, 360 MPa, etc
- These alloys are press quenchable and typically have extrudability similar to 6082 or slightly worse
- Talk to your extruder if interested

Dimensional Considerations

- Lineals are typically 25 – 50 meters in length as extruded
- Process and quench cause dimensional variations down the extrusion length
 - Stretching operations reduces these but does not eliminate them



Dimensional Considerations

- ANSI H35.2 / H35.2(M) has standard extrusion tolerances “for the typical profile”
- Talk to your extruder to understand what is possible for *your* profile
 - Know what is critical to form, fit, or function, and let the extruder know so they can focus on those characteristics
- Profile, alloy, and temper will define the metallurgical quench requirements
 - The resulting dimensions will be strongly impacted by the quench method and quench rate
- Alloys that are less “quench sensitive” can meet requirements with lower quench rates
 - Lower quench rates mean less distortion, which means better dimensional control

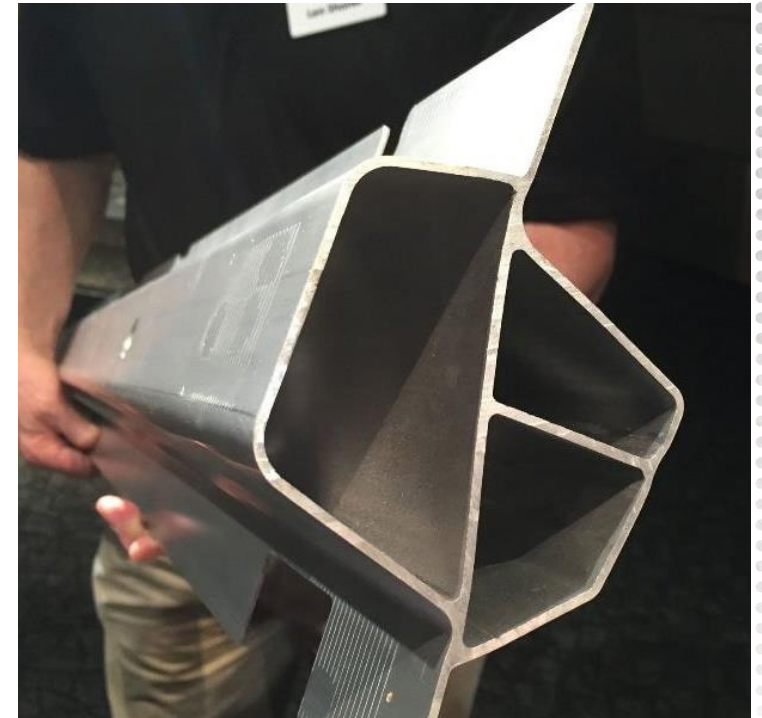
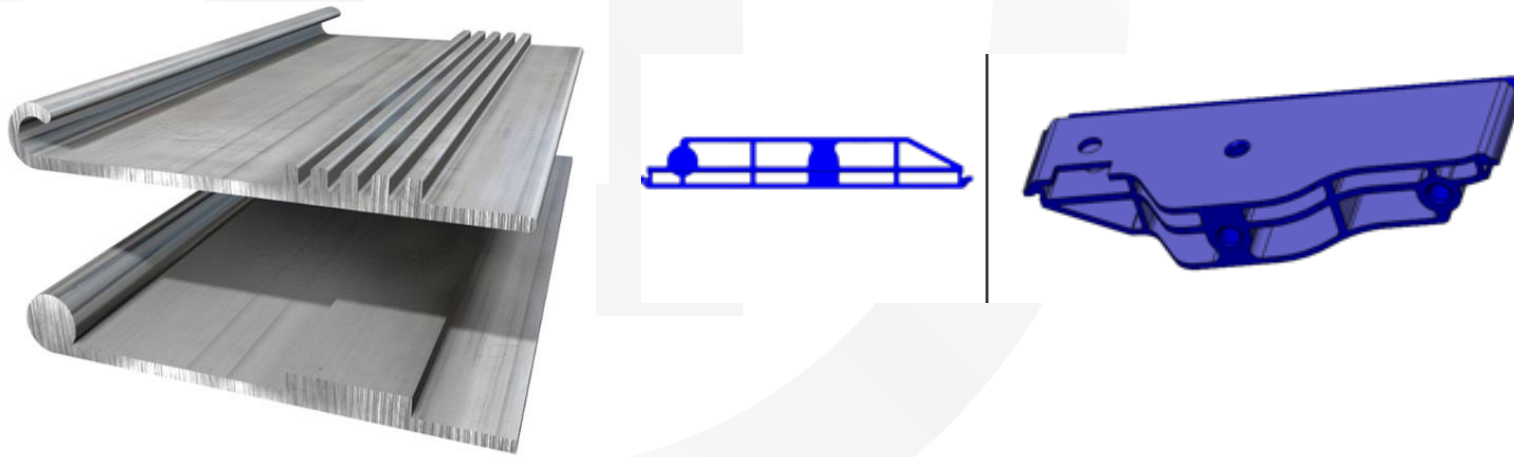
Dimensional Considerations

- The Aluminum Association has a series of videos describing extrusion tolerances and how they are measured
 - [The Aluminum Association - YouTube](#)
- Extrusion tolerances are not the same as GD&T and often need to be correlated



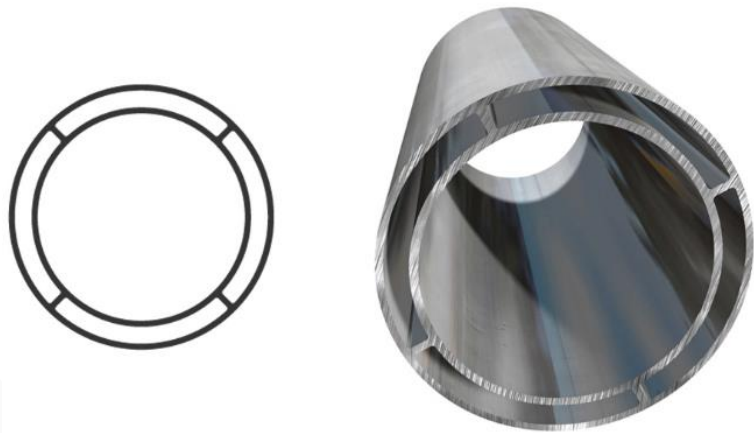
Extrusion Possibilities are Endless

- Extrusion has several advantages
 - Relatively low tooling cost
 - Nearly unlimited shapes are possible
 - Ability to put the metal where it's needed

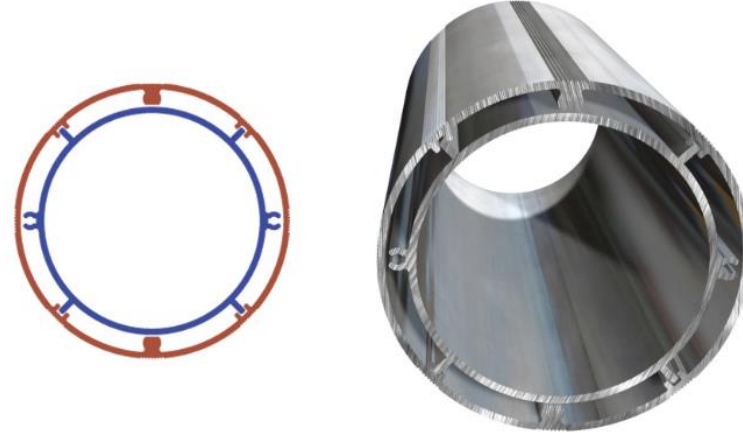


Extrusion Possibilities are Endless

- It's better to involve the extruder up front
 - Is there an easier way to achieve the same results?



- Multi-void hollow
 - High tool cost
 - Low productivity (high cost)



- 2 profiles, both single void hollows
 - Lower total tool cost
 - High productivity (lower cost)

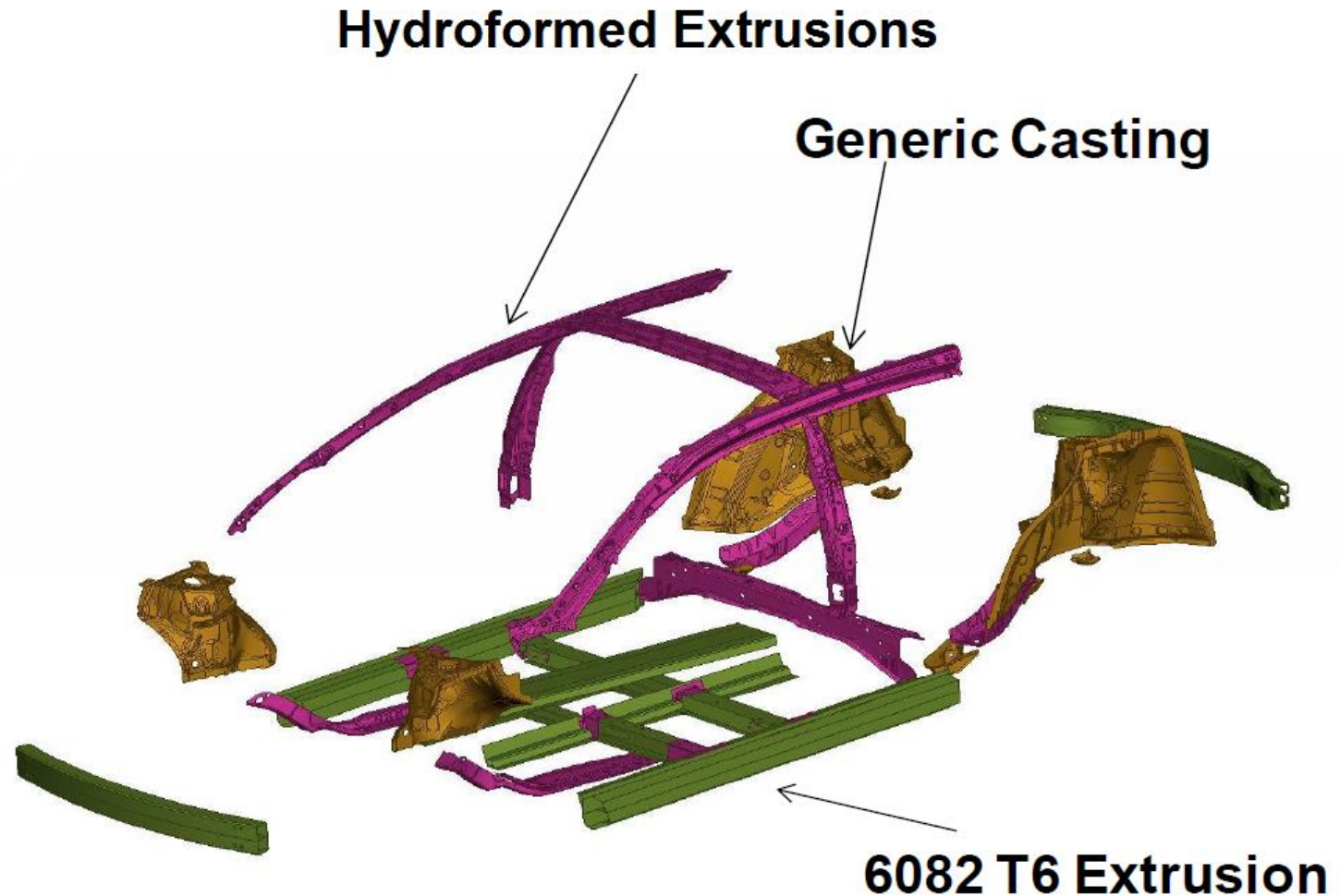
Pop Quiz

Identify the features extruded into this profile



Examples of BIW Use of Extrusions

The earlier an extruder is involved the more options are possible

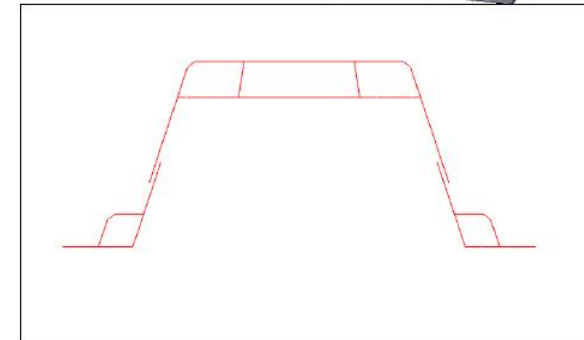
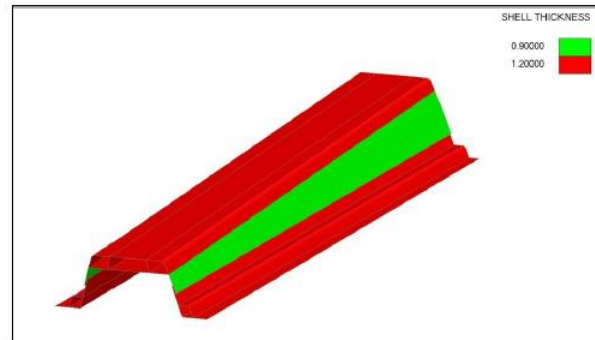
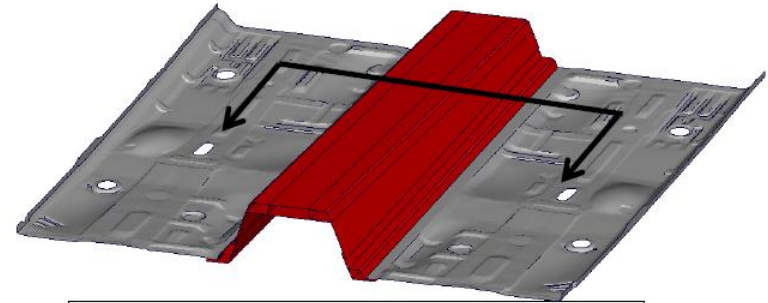
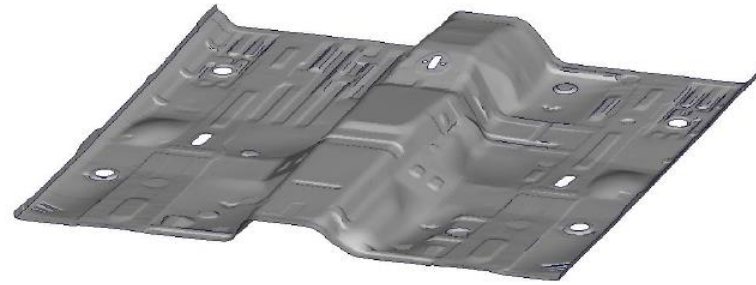


Source: *VENZA Aluminum BIW Concept Study*

Using Extrusion's Strengths in Design

This example is not optimized

- Locally increase wall thickness
- Mounting features
- Different alloys for each part



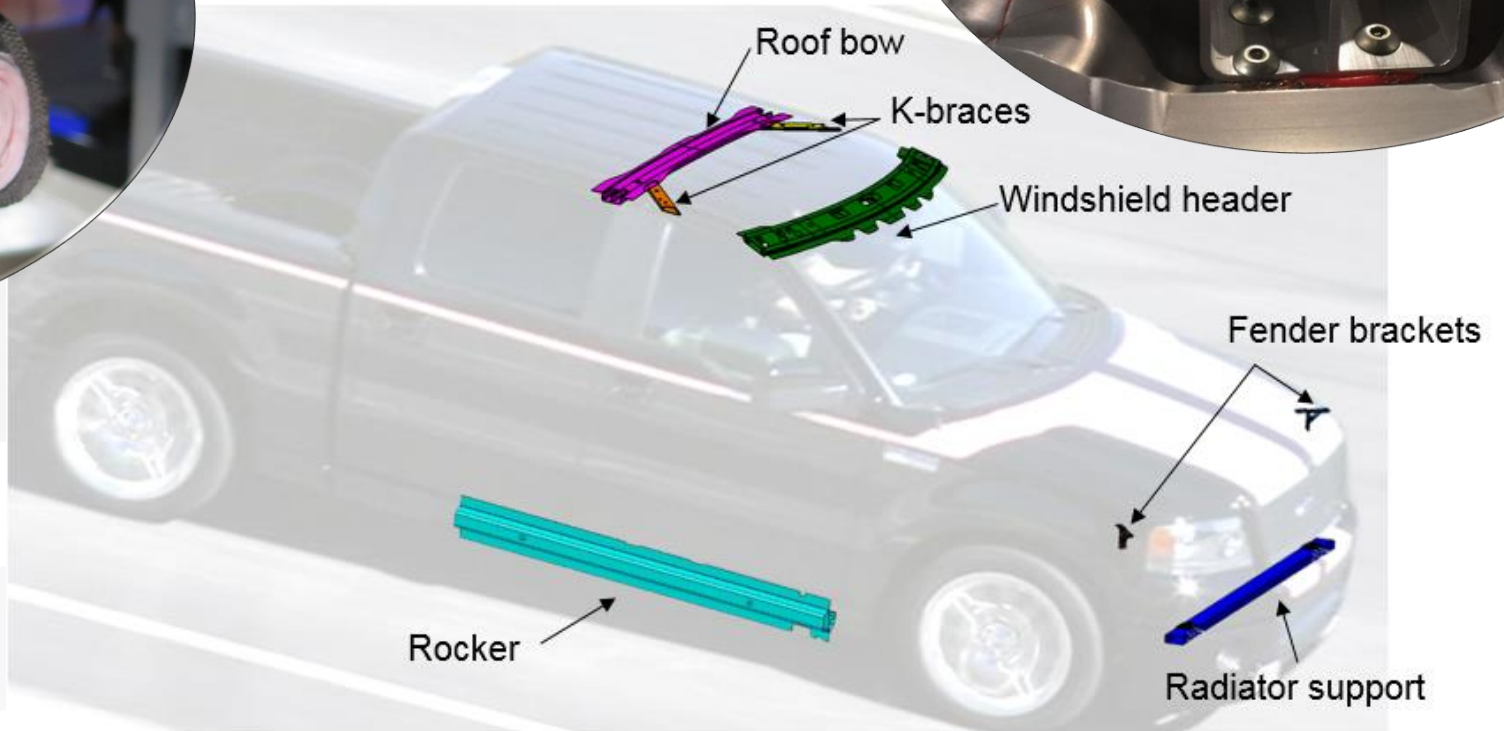
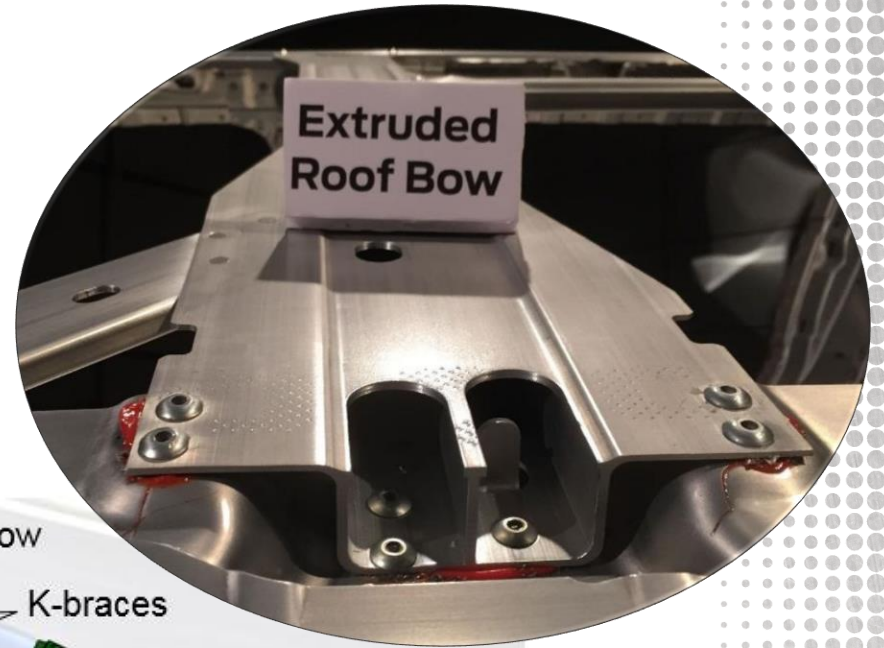
Extrusion tunnel cross section

Source: VENZA Aluminum BIW Concept Study

Using Extrusion's Strengths in Design

- Design with extrusions in mind – clean sheet
- Wall thicknesses can be adjusted across the profile but not down the length
- Remember extrusions can be designed to fit together – a one piece design may not be the most cost-effective or best option
 - Different characteristics in different locations
- Understand the stress state of the end use can influence seam weld location
 - If critical, review seam weld location with the extruder
- Extrusion allows you to “put the metal where it’s needed”
 - Screw bosses, locator marks, slugs for tapping, etc.

Ford F-150



Source: "Building the 2015 Ford F-150 Safe and Strong," www.trucktrend.com

BMW i3

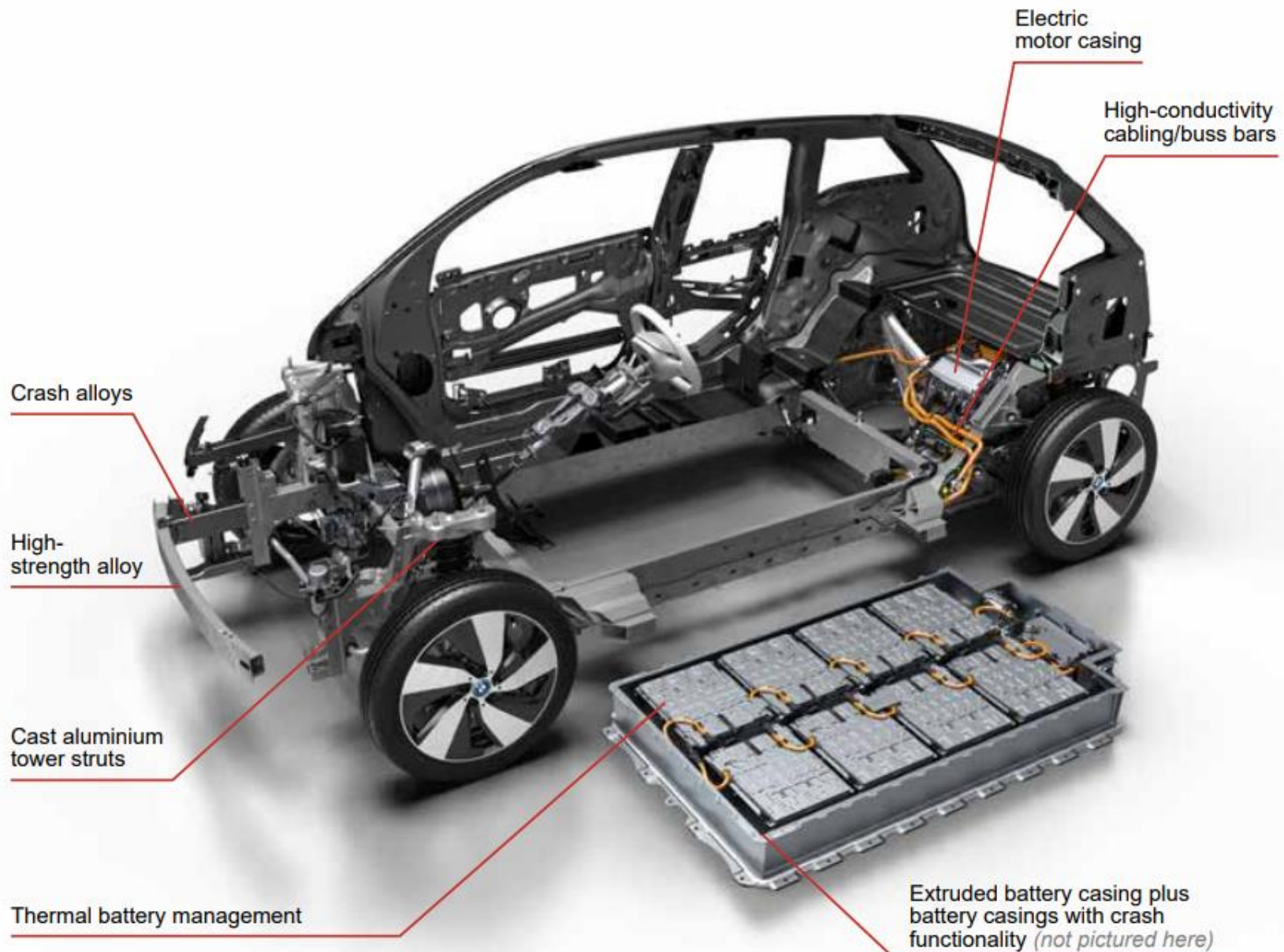
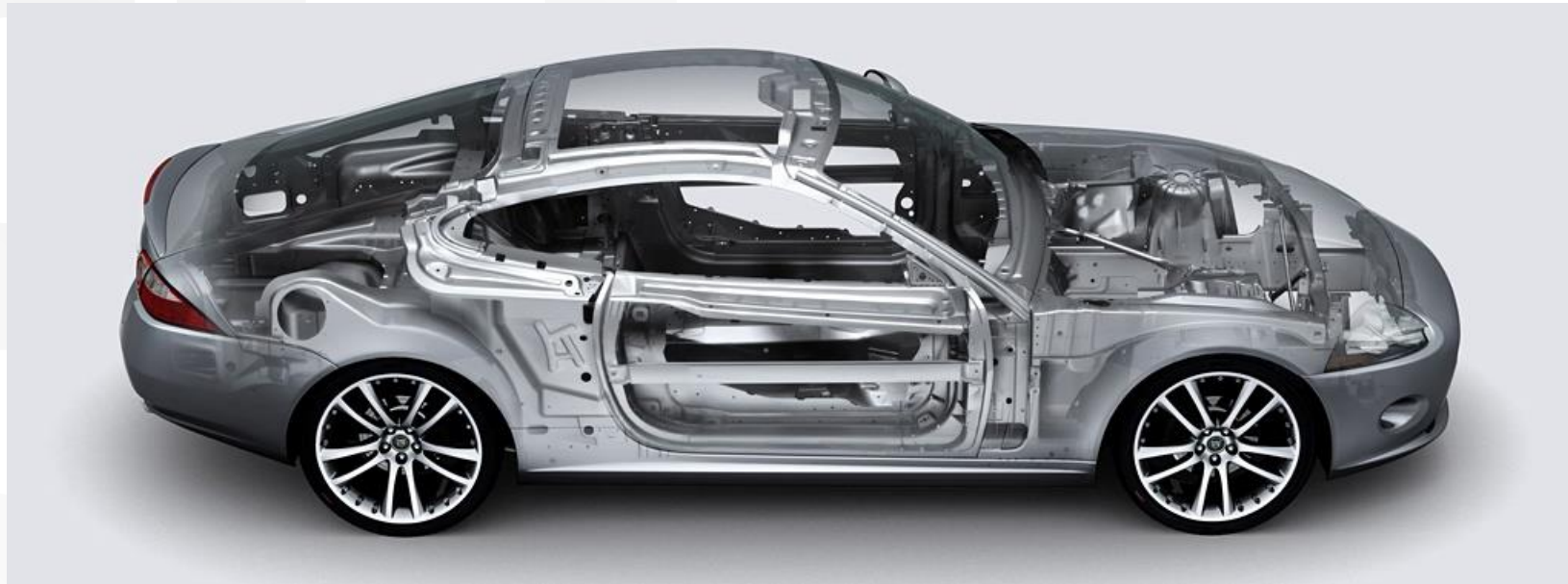


Illustration: BMW AG

Extrusion Summary

- Extrusion is a hot working process that produces profiles with a constant cross section
- Wide variety of profiles and design features can be extruded
- Large selection of extrusion alloys, allowing for targeting specific design goals
 - Cost, geometric shape, properties, fabrication integration, etc.



Extrusion Summary

- Best to have discussions with the extruder early in process; They are the subject matter experts and can offer suggestions to improve performance
- Most automotive-focused extrusion companies are:
 - ISO-9001 certified (several of IATF-16949 certified)
 - Familiar with automotive quality and delivery expectations
 - Able to support at the design stage
- Many extruders offer more than just raw materials
 - Custom alloys for demanding automotive applications
 - Modelling
 - Fabrication
 - Kitting & assembly
 - Specialized coatings
 - One-stop shop



Questions?