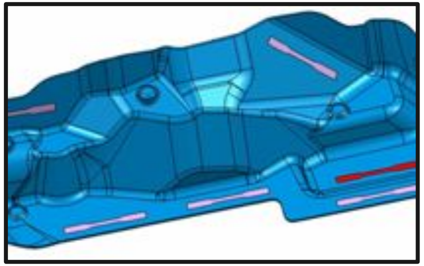
A QUALITY APPROACH TO MATERIALS SELECTION AND DEVELOPMENT

GLOBAL AUTOMOTIVE LIGHTWEIGHT MATERIALS EUROPE 2017

Robert Best
25 April 2017

A Quality Approach to Materials Selection and Development

Contents



JAGUAR LAND ROVER
Our Business

14 vehicle lines.

3 UK vehicle assembly plants, 1 engineering and manufacturing centre and 2 UK design and engineering sites.

40,000 people globally – headcount has almost doubled over the last five years.

Plants in China, India and Brazil.

Employs over 10,000 engineers and designers.

Sales network in 136 countries.

Jaguar Land Rover is the largest automotive employer in the UK.

201 awards won in 2016.

JAGUAR LAND ROVER

In The UK Economy

No1

LEADING PREMIUM AUTOMOTIVE BUSINESS IN THE UK

- The only volume manufacturer of luxury vehicles in the UK
- The largest investor in automotive R&D and engineering in the UK

A MAJOR PROVIDER OF HIGHLY SKILLED JOBS IN THE UK

- Jaguar Land Rover is the largest automotive employer in the UK
- Supports up to 275,000 people through the supply chain, dealer network and wider economy
- Recruited 24,000 people since 2010

ONE OF THE UK'S LARGEST EXPORTERS BY VALUE

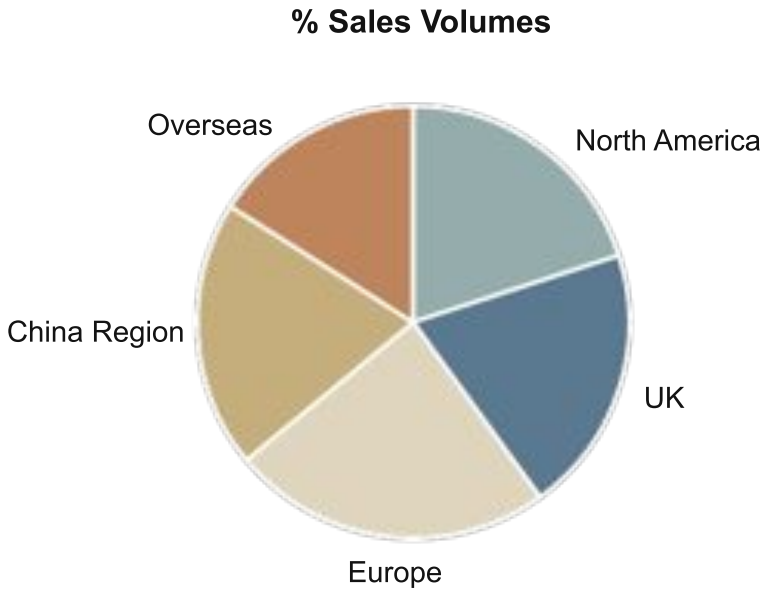
- Almost 80% of production exported from three plants in the UK

LED BY ADVANCED DESIGN, ENGINEERING AND TECHNOLOGY

- Has a world-class team with over 10,000 engineers and designers
- Invests £150 million in an advanced research facility together with Warwick Manufacturing Group and TMETC at University of Warwick to accelerate innovation
- £1billion investment in state-of-the-art advanced engine facility

JAGUAR LAND ROVER
2016 Full Year Global Sales Results*

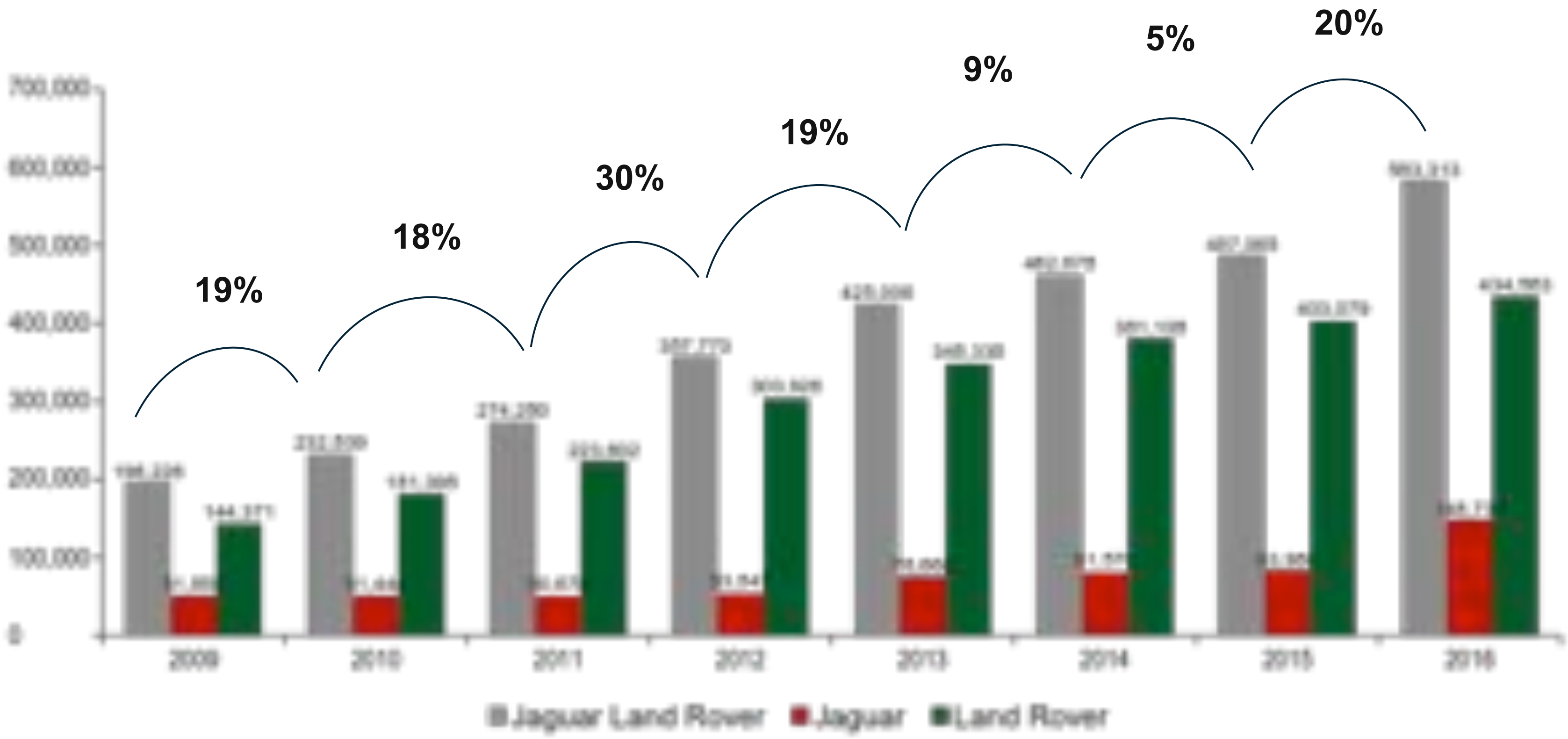
Market	Sales	% vs. prior year	% sales volume
North America	117,278	25%	20%
UK	117,571	17%	20%
Europe	138,695	26%	24%
China Region	119,049	31%	20%
Overseas	90,720	(0.5%)	16%
Total	583,313	20%	100%



*Including CJLR sales

SUSTAINED GROWTH

Driven By Great Products



JAGUAR PRODUCT LINEUP

XJ

The XJ is a dramatic combination of beauty, luxury and power

XF

Sleek, dynamic, daring, XF is a fusion of sports car styling with outstanding comfort

XE

The most advanced, efficient and refined sports saloon that Jaguar has ever produced

I–PACE

The Jaguar I-PACE Concept is the first step towards our future

XFL

Developed exclusively for China, the all-new XFL delivers unparalleled passenger luxury and technology

F–TYPE

Powerful, agile and distinctive, F-TYPE is a true Jaguar sports car

F–PACE

The all-new Jaguar F-PACE: a performance crossover from Jaguar for those who love driving

LAND ROVER PRODUCT LINEUP

New Discovery

The best family SUV in the world, with unrivalled capability and technology

Discovery Sport

The first in a new generation of Land Rover SUV design

Range Rover Velar

The first vehicle of it’s kind; another pioneer, exploring the frontier for luxury SUVs

Range Rover Evoque

Distinctive and individual, a true Range Rover in compact form

Range Rover Evoque Convertible

Land Rover's latest luxury convertible SUV

Range Rover Sport

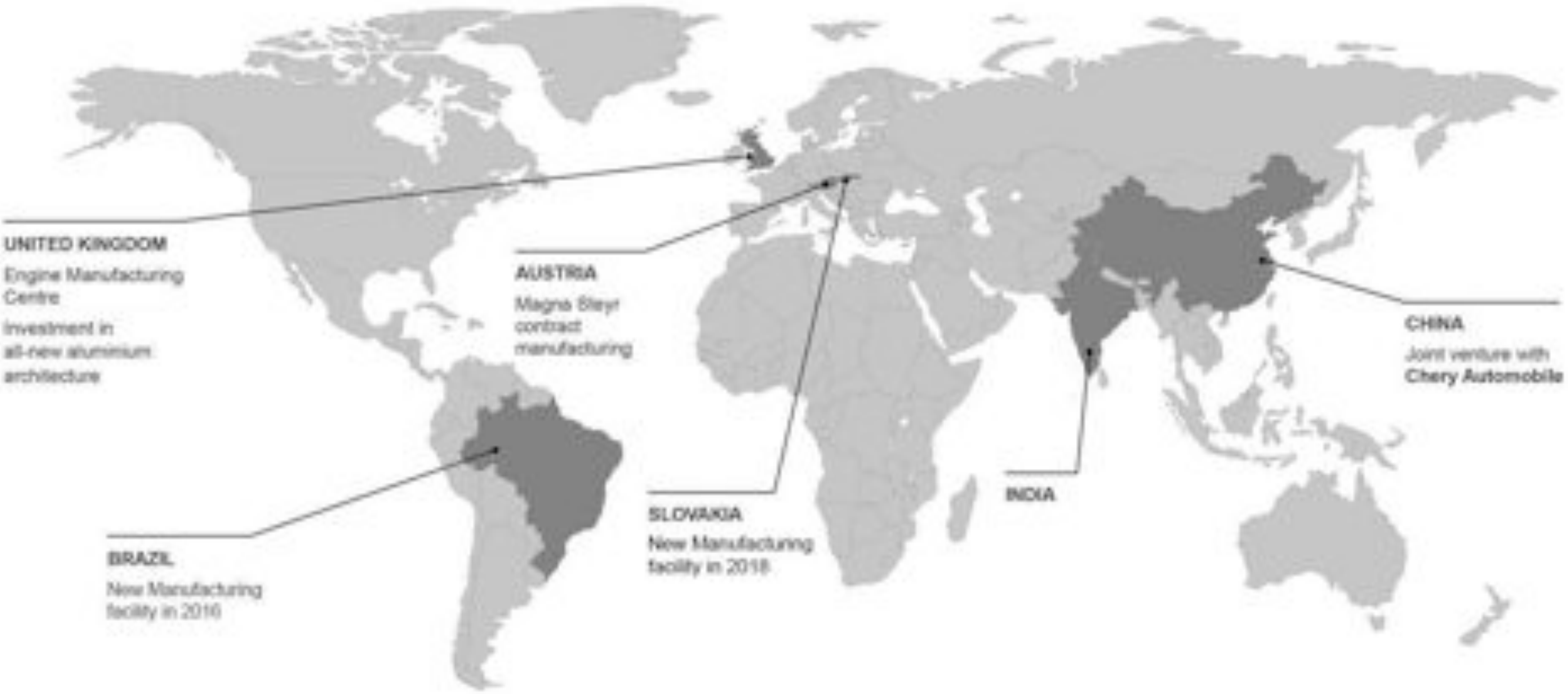
The most agile and dynamic Land Rover

Range Rover

The pinnacle of refined capability

JAGUAR LAND ROVER
Manufacturing and Product Development Facilities

GLOBAL INVESTMENT IN INFRASTRUCTURE

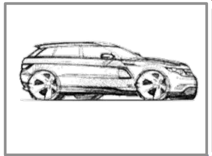


BODY MATERIALS – KEY BUSINESS DRIVERS

Design	– Quality, premium segment vehicle
Performance	– Fun to drive
Capability	– Reliability and durability
Sustainability	– Economic plus environmental
Supply	– Global availability, global production

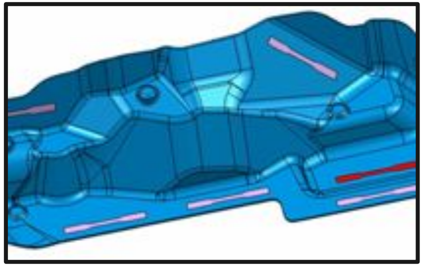
BODY MATERIALS – KEY BUSINESS DRIVERS

Body Materials to meet Business Drivers

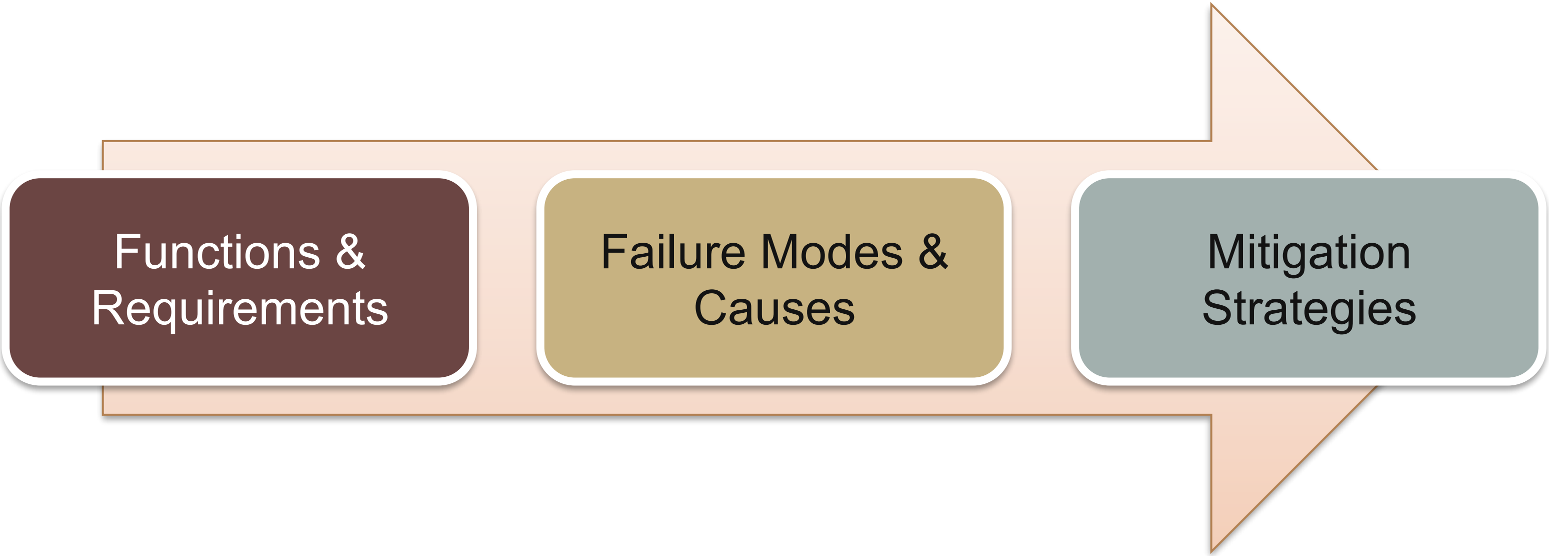
	Business Driver	Material Requirement
	**Design** • Quality, premium segment vehicle	➢ Advanced high-form materials ➢ Improved visual quality
	**Performance** • Fun to drive	➢ Mixed-material architectures - right material right place ➢ Advanced high strength materials
	**Capability** • Reliability and durability	➢ Manage corrosion and durability ➢ Develop and implement design guidelines
	**Sustainability** • Economic plus environmental	➢ CO_2 impact ➢ Recyclability ➢ Cost of production
	**Supply** • Global availability, global production	➢ Equivalencies of local materials on global scale ➢ Supply route approvals

A Quality Approach to Materials Selection and Development
Contents

- Jaguar Land Rover Overview
- Failure Mode Avoidance
  - Functions & Requirements
    - Case Study 1: Cosmetic Castings
  - Failure Modes & Causes
  - Mitigation Strategies
    - Case Study 2: Corrosion in Mixed-Metal Structures
- Uses of FMA Tool
  - FMA for Materials Selection
    - Case Study 3: Supply Route Approval
- Summary



A Quality Approach to Materials Selection and Development
Failure Mode Avoidance – Functions & Requirements



A Quality Approach to Materials Selection and Development

Failure Mode Avoidance – Functions & Requirements

Coil Production

Casting

Blanking & Forming

Body Assembly

Paint + Trim & Final

In-Service

End-of-life

A Quality Approach to Materials Selection and Development

Failure Mode Avoidance – Functions & Requirements

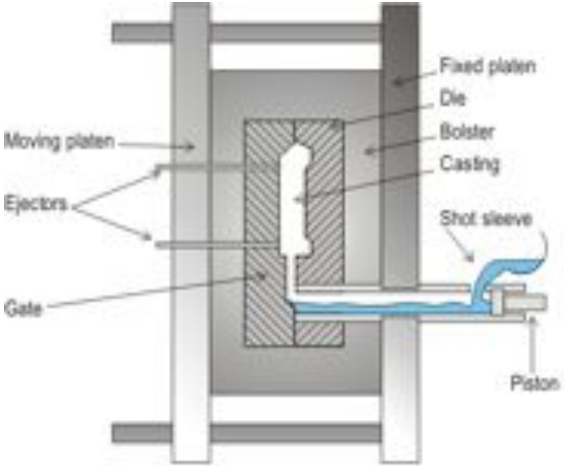
Functional Step	Requirement
 Coil Production	▪ In-coming strength ▪ Free from visual defects ▪ …
 Blanking & Forming	▪ Dimensional tolerances ▪ Free from visual defects ▪ Meet production metrics (e.g. hits per hour)
 Body Assembly	▪ Enable joint strength ▪ Meet production metrics (e.g. cycle time) ▪ …
 Paint + Trim & Final	▪ Visual quality ▪ Chemical compatibility (contamination) ▪ …

Functional Step	Requirement
 In-service	▪ Static strength ▪ Dynamic strength ▪ Stiffness ▪ Visual quality ▪ Crash performance ▪ …
 End-of-Life	▪ Recyclability / Re-use ▪ …

CASE STUDY 1: COSMETIC CASTINGS

A Quality Approach to Materials Selection and Development
Case Study 1: Cosmetic Castings

- High-Pressure Die Casting (HPDC)
  1. Measured quantity of molten metal poured into shot sleeve
  2. Hydraulically injected at high-pressure into mould
  3. Metal rapidly solidifies and part ejected



- Used throughout automotive industry in aluminium intensive & mixed-material structures
  - Aluminium
    - Front Shock Tower; Rear Swan-neck
  - Magnesium
    - Front End Carrier; Cross-car Beam

A Quality Approach to Materials Selection and Development
Case Study 1: Cosmetic Castings

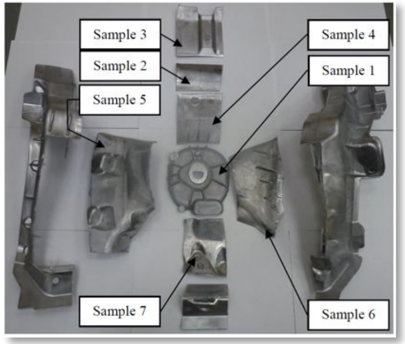
- Casting defects can occur on parts as die wears
  - Due to thermal fatigue and liquid metal erosion
  - Manifests as nibs (pips) and heat checks on cast part

- Defects can be unacceptable on two accounts:
  - Safety – Of operator during assembly (nibs)
  - Cosmetic – When used in visible locations surface must have satisfactory aesthetics

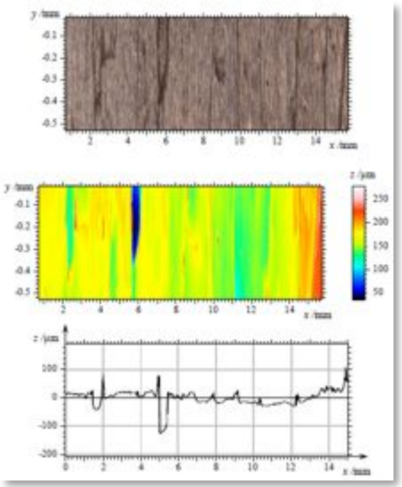
- Requirement for **Visual Quality (aesthetics)** not well defined
  - Previous castings were not visible to customer

A Quality Approach to Materials Selection and Development

Case Study 1: Cosmetic Castings



1. Agreed threshold / boundary samples
   - Plant Quality – Voice of Customer



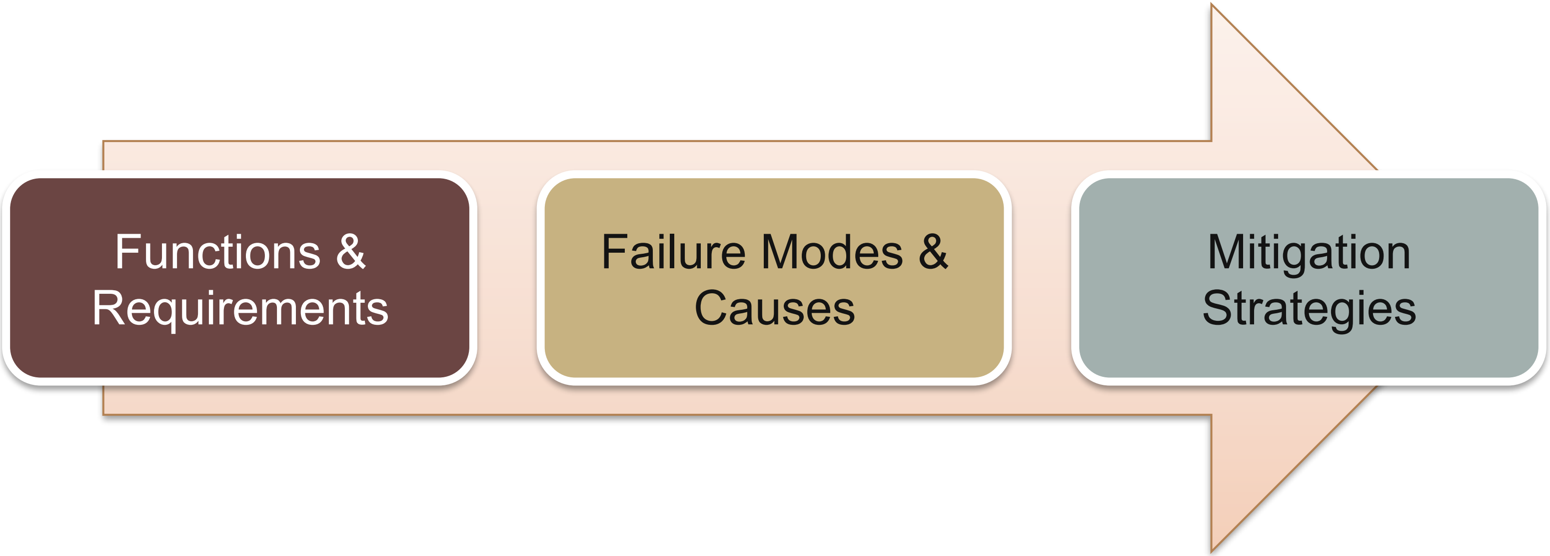
2. Characterised surfaces and defects
   - In collaboration with National Physical Laboratory (NPL)


Title: High Pressure Die Cast Aluminium Components for Structural BIW Applications

3. Developed specification and disseminated to supply base

A Quality Approach to Materials Selection and Development

Failure Mode Avoidance – Failure Modes & Causes



A Quality Approach to Materials Selection and Development
Failure Mode Avoidance – Failure Modes & Causes

Causes

Material Properties
- In-coming supply variation – Aging
- Evolution – stamping/paint-bake

Part Design
- Geometry effects – stress-raisers/corrosion
- Joining techniques – Local property variation. Geometric stress-raisers

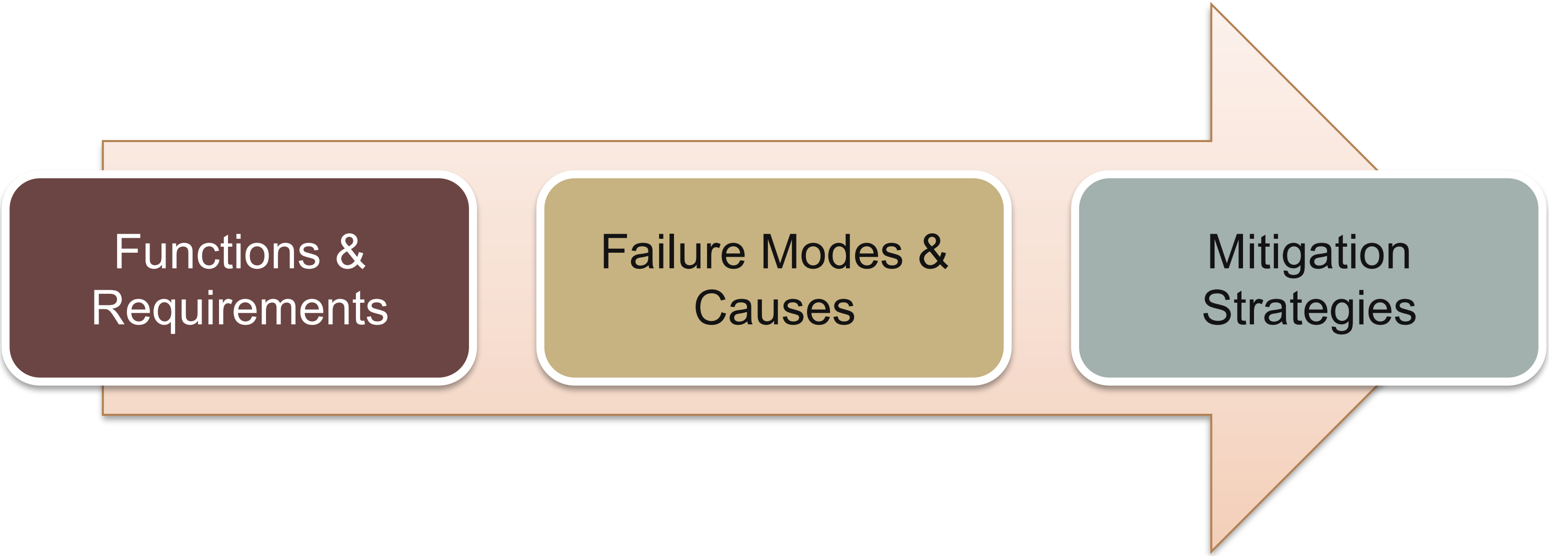
Failure Mode: Strength requirement not met

Introduced Defects
- Manufacturing – coil production/stamping
- In-service – stone-chipping

Part Properties
- Changes over time – corrosion/fatigue

A Quality Approach to Materials Selection and Development

Failure Mode Avoidance – Mitigation Strategies



A Quality Approach to Materials Selection and Development
Failure Mode Avoidance – Mitigation Strategies

Detection via Material Approval & Characterisation

- Testing against requirements
- Characterisation to generate design data

Prevention via Part Design

- Material selection strategies
- Design rules / guidelines
- Working practices / procedures

Prevention via Routine Controls

- Coil release testing against specification
- Compliance checklists
- Inspection processes
- Process capability monitoring

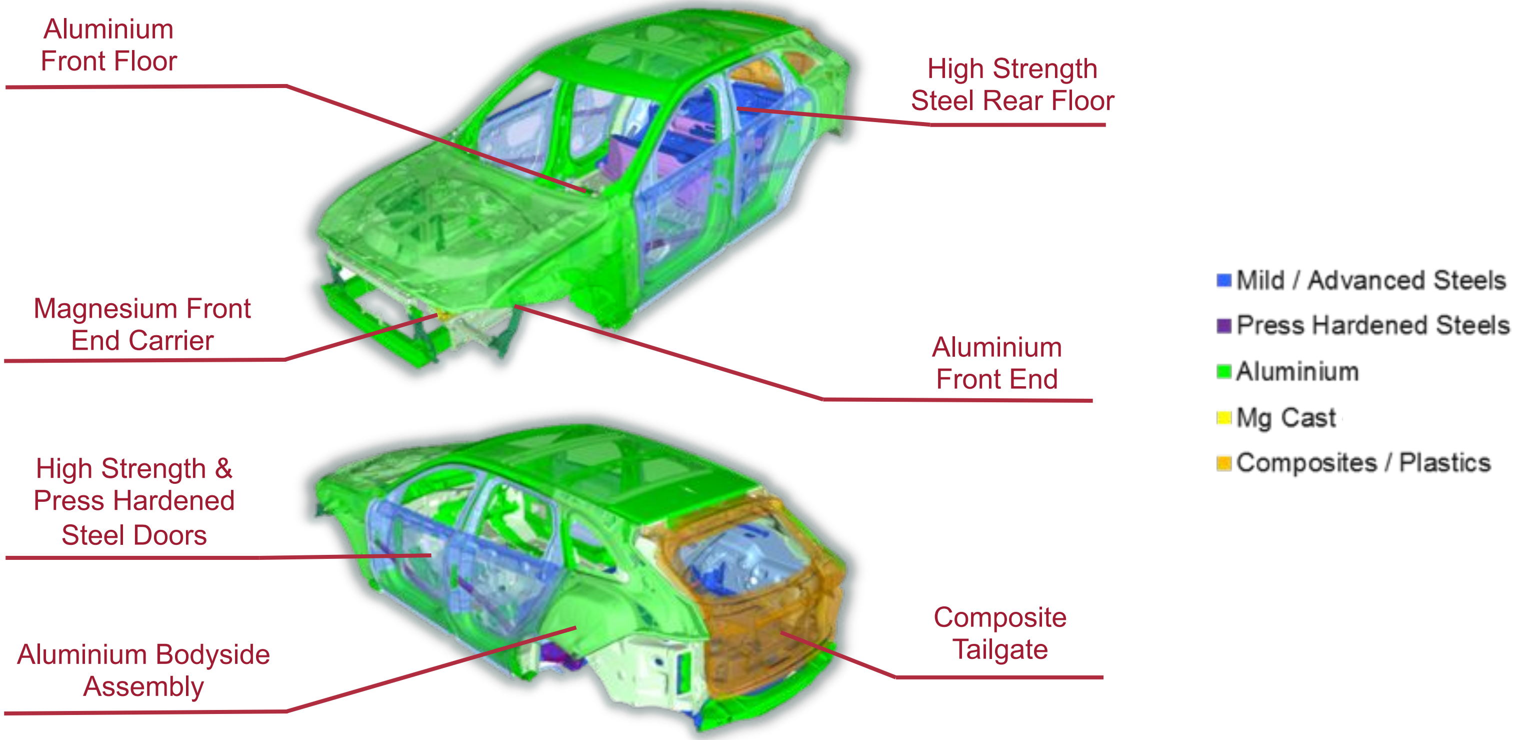
Identify material failure modes and/or causes

Manage issues identified during Material Approval process

CASE STUDY 2: CORROSION IN MIXED METAL STRUCTURES

A Quality Approach to Materials Selection and Development

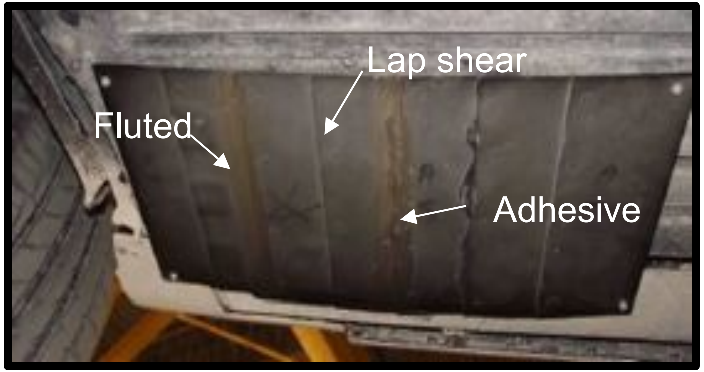
Case Study 2: Corrosion in Mixed Metal Structures



New vehicle architecture utilised multi-material approach to the body, enabling a stiff, weight efficient construction. **Right Material in Right Place.** But introduces additional Failure Modes.

A Quality Approach to Materials Selection and Development
Case Study 2: Corrosion in Mixed Metal Structures

- Mixed-metal joints evaluated on test vehicle (12 week test)
- Test plaques mounted on side doors (vertical orientation) and underbody (horizontal orientation) of a test vehicle



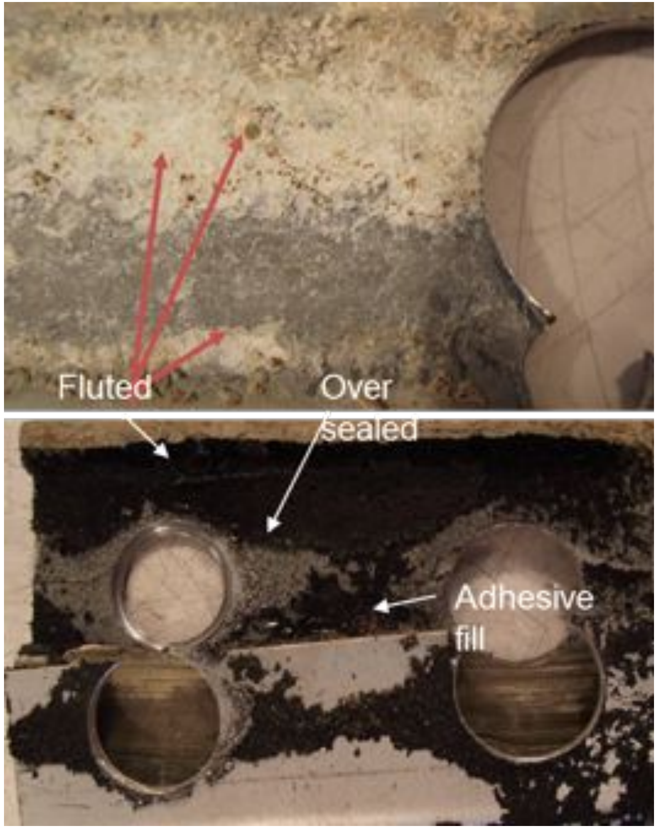
- Combinations of bake-hardening steel, 6xxx and 5xxx aluminium in unsealed, sealed and fluted joint configurations

- Two types of adhesive evaluated
- Joints with and without overseal included

A Quality Approach to Materials Selection and Development

Case Study 2: Corrosion in Mixed Metal Structures

- Corrosion in all unsealed areas. High Risk
- Adhesive coverage in fluted joints retains moisture and promotes corrosion initiation. Moderate Risk – flute geometry optimised for good e-coat coverage
- Dirt ingress to lap joint where adhesive does not seal the edge promotes crevice corrosion. Moderate Risk – managed by controlling squeeze out
- Over-sealing robustly seals the lap joint and protects against corrosion. Low Risk
- Comparable performance of horizontal and vertical mounted test plaques



A Quality Approach to Materials Selection and Development

Case Study 2: Corrosion in Mixed Metal Structures

Mitigation Strategies

Detection via Material Approval

- **Specification Requirements**
  - Cabinet-based component level tests (e.g. NSS, CCT, Filiform, CASS)
  - Vehicle Corrosion Test for Engineering sign-off

Prevention via Part Design

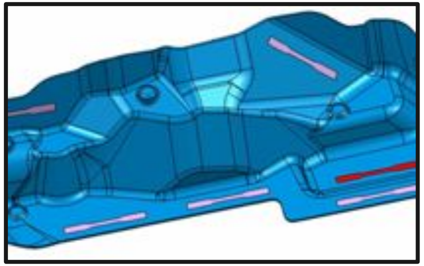
- **Design Rules**
  - Joint geometry, adhesive fill, e-coat coverage, use of wax
- **Best Practice Guidelines**
  - Lessons learned
- **Standards & Procedures**
  - Coating weights, corrosion requirements

Research & Development

(continuous improvement)

- **Test Method Development**
  - JLR Cyclic Corrosion Test (replication of on-vehicle failure modes).
- **Corrosion Strategy Refinement**
  - Vehicle corrosion sensor development (define corrosion risk zones in the vehicle)

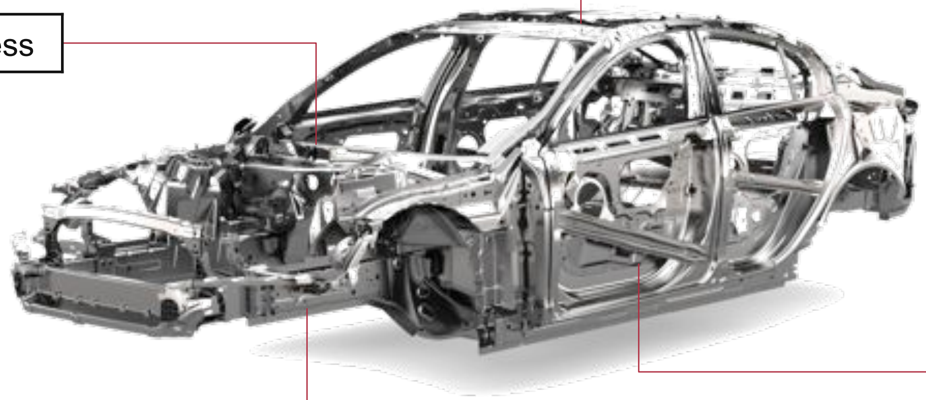
A Quality Approach to Materials Selection and Development
Contents



A Quality Approach to Materials Selection and Development

Use of FMA Tool – Materials Selection

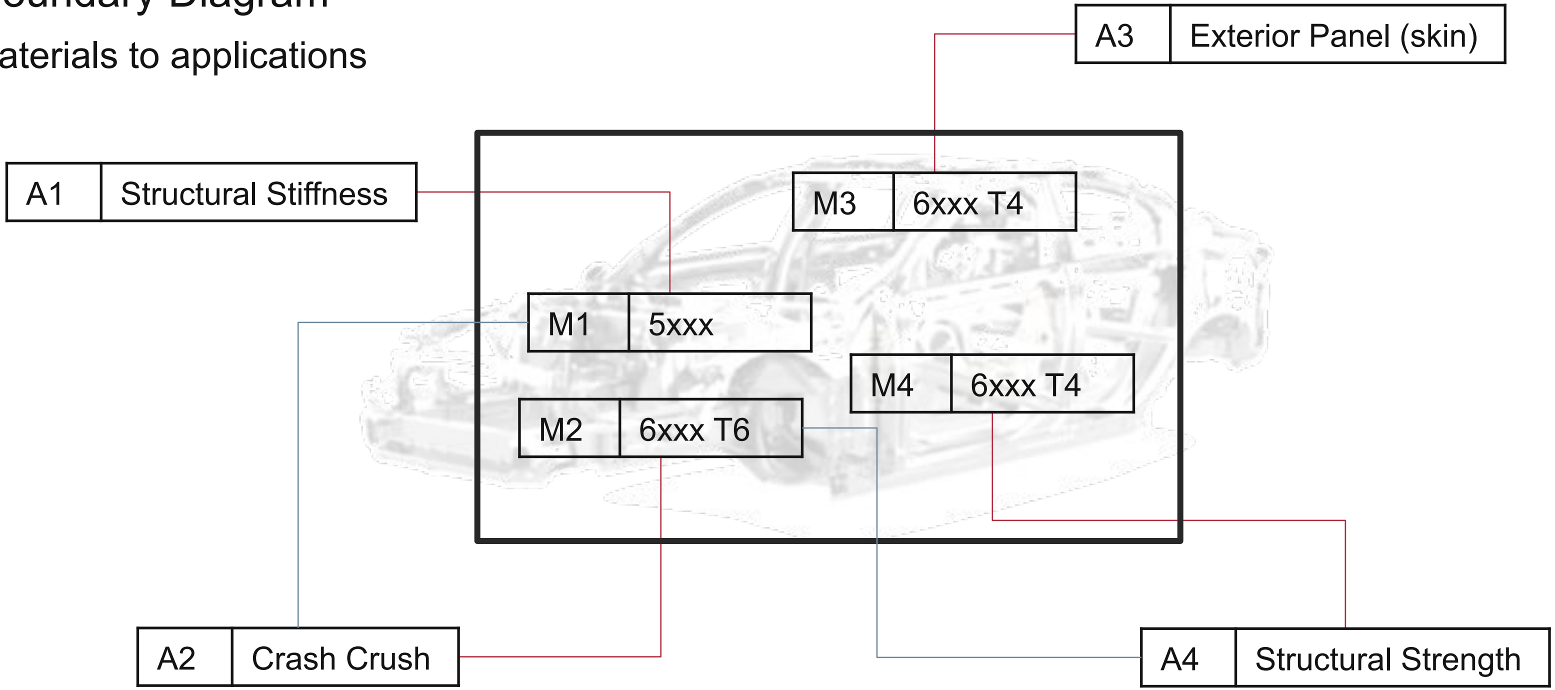
- To use FMA tool for Materials Selection
  - Consult Boundary Diagram
    - Aligns materials to applications



A Quality Approach to Materials Selection and Development

Use of FMA Tool – Materials Selection

- To use FMA tool for Materials Selection
  - Consult Boundary Diagram
    - Aligns materials to applications



A Quality Approach to Materials Selection and Development

Use of FMA Tool – Materials Selection

- To use FMA tool for Materials Selection
  - Consult Boundary Diagram
    - Aligns materials to applications
  - Cross-reference application requirements against candidate materials
    - If applicable, rank performance of candidates against requirements

	Manufacturing			In-Service			
Candidate Material	Requirement 1	Requirement 2	Requirement 3	Requirement 4	Requirement 5	Requirement 6	Requirement 7
A	✓	=	=	=	✓	=	✓
B	✗	✓	=	✓	✓	✓	✓
C	=	=	=	=	=	=	✓

Key

= Requirement Met

✓ Requirement Exceeded

✗ Requirement Not Met

A Quality Approach to Materials Selection and Development

Use of FMA Tool – Materials Selection

- To use FMA tool for Materials Selection
  - Consult Boundary Diagram
    - Aligns materials to applications
  - Cross-reference application requirements against candidate materials
    - If applicable, rank performance of candidates against requirements

  - Individual material selection exercise will also incorporate project specific requirements such as:
    - Cost
    - Availability
    - Bill of Process / Bill of Design
    - Regulations
    - …

CASE STUDY 4: CASTING MATERIAL APPROVAL

A Quality Approach to Materials Selection and Development
Case Study 3: Casting Material Approval

Business Need

- Lower cost castings

Proposed Solution

- New casting material which does not need strengthening heat-treatment

Requirements

- Meet current casting application requirements

Process

- FMA used to identify significant characteristics and define suitable test programme
  - Case Study looks at **Strength** only

Functional Step	Requirement
 Casting	▪ In-coming strength ▪ Free from visual defects
 Body Assembly	▪ Enable joint strength ▪ Meet production metrics (e.g. cycle time)
 Paint + Trim & Final	▪ Visual quality ▪ Chemical compatibility (contamination)
 In-service	▪ Static strength ▪ Dynamic strength ▪ Stiffness ▪ Visual quality
 End-of-Life	▪ Recyclability / Re-use

A Quality Approach to Materials Selection and Development

Case Study 3: Alternative Casting Supply Route

Requirement	Failure Mode	Cause	Mitigation (Test Programme)
Must meet in-service **static strength** requirements	Yield strength requirement not met	Yield strength too low due **to internal defects**	▪ **Microstructural Analysis** – Adjacent to tensile test locations
		Yield strength too low due to **elemental segregation**	▪ **Tensile testing** and **Chemical Analysis** – comparison across part and in varying thickness material
		Yield strength too low due to **variations in part thickness**	▪ **Tensile Testing** across part and in varying thickness material for “new” material and material aged for 3 months
		Yield strength too high due to **aging**	
		Yield strength too low due to **incorrect heat treatment**	▪ *Not relevant: no heat treatment in this case*
		Yield strength too low due to **incorrect chemistry**	▪ **Chemical Analysis** – comparison between melt chemistry, bulk chemistry and surface chemistry

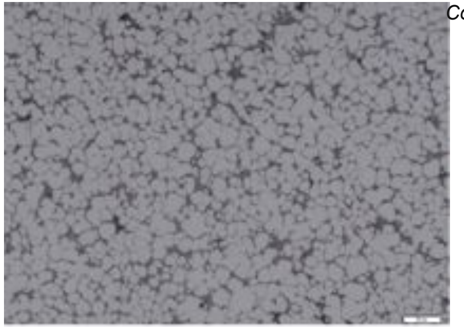
A Quality Approach to Materials Selection and Development
Case Study 3: Casting Material Approval

Chemical Analysis Results

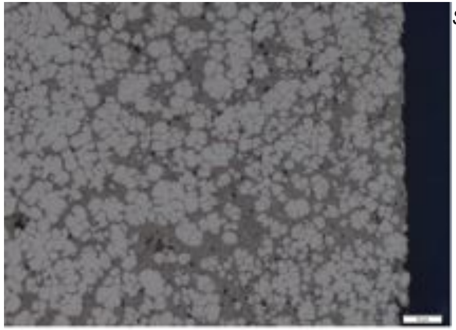
- Confirmed as AlMgSi alloy
- Variation in chemistry through thickness; high silicon content at surface
  - Typical of HPDC aluminium alloy

Microstructural Analysis Results

- Microstructural images taken at regular intervals through thickness across part
- Variation through thickness consistent with variation in composition
- Aluminium solid solution with interdendritic silicon eutectic and intermetallic particles
  - Typical of HPDC aluminium alloy



Core



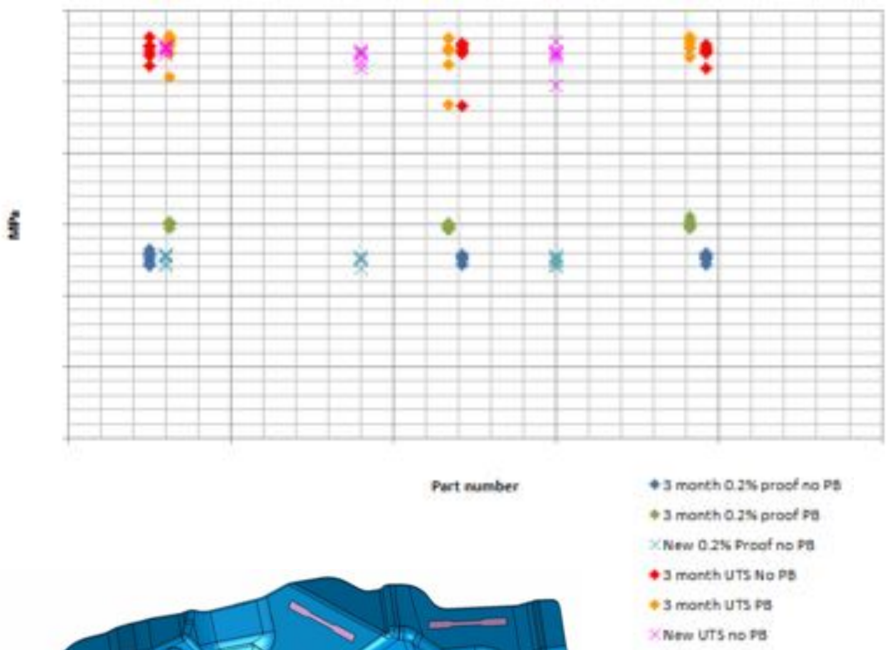
Surface

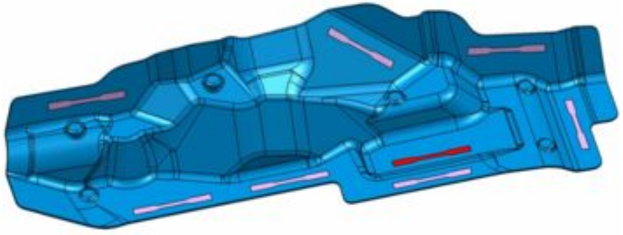
A Quality Approach to Materials Selection and Development

Case Study 3: Casting Material Approval

<u>Tensile Test Results</u>

- Consistency across batch
  - Parts selected at random from beginning, middle and end of batch
- Consistency across part
  - Tensile tests in 8 locations across part
- No discernible effect of aging between new parts and 3 months old
- Larger effect of paint-bake on proof strength than UTS
  - Typical of HDPC aluminium alloy
  - All results meet requirements of casting specification





A Quality Approach to Materials Selection and Development

Case Study 3: Casting Material Approval

<u>Conclusion</u>

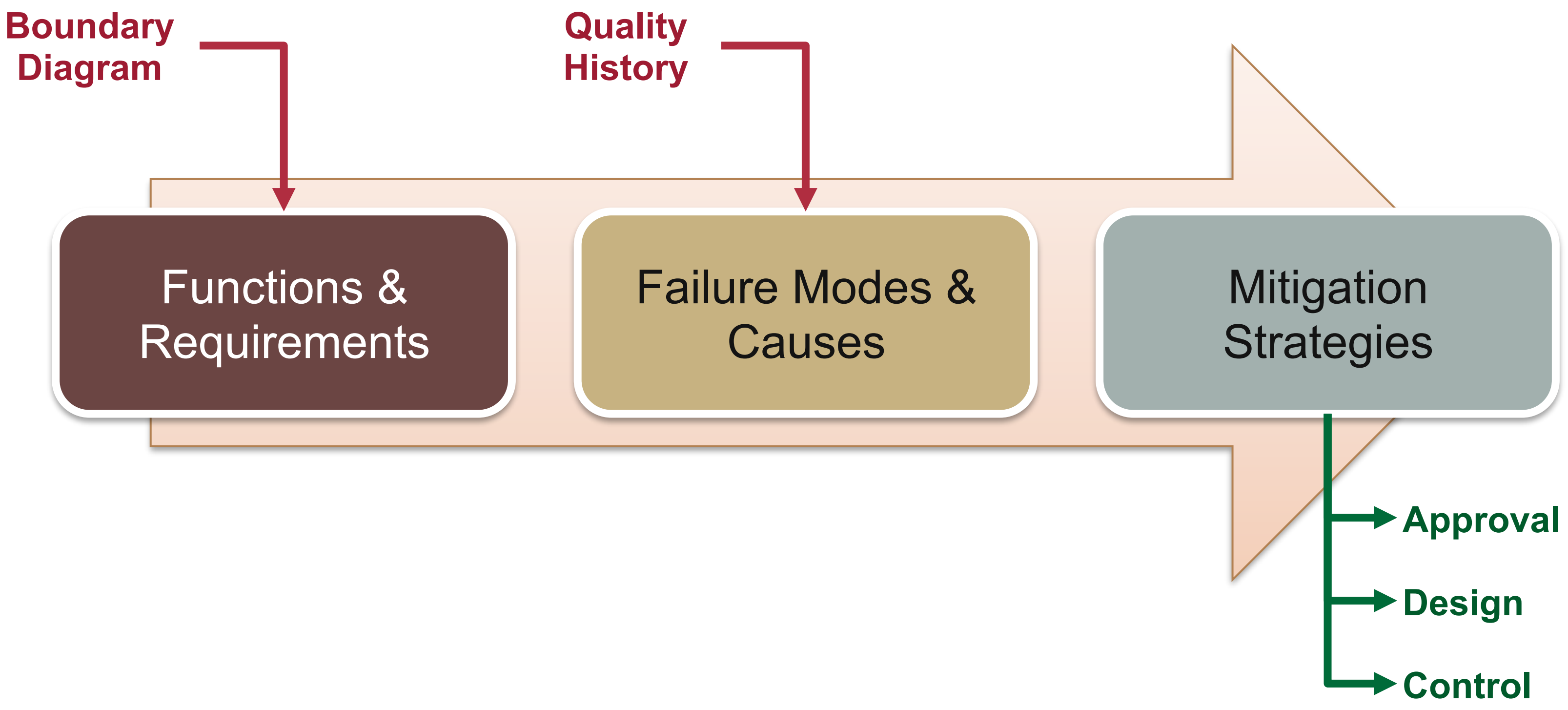
- FMA used to define test programme based on functional requirements of material in application

- For example, to evaluate In-Service Static Strength requirement, following assessments were made:
  - Chemical analysis
  - Microstructural analysis
  - Tensile testing

- In this case:
  - All requirements were met with new alloy
  - No additional failure modes or causes were identified

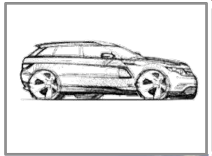
A Quality Approach to Materials Selection and Development

Failure Mode Avoidance – Summary



BODY MATERIALS – KEY BUSINESS DRIVERS

Body Materials to meet Business Drivers

	Business Driver	Material Requirement
	**Design** • Quality, premium segment vehicle	➢ **Advanced high-form materials** ➢ Improved visual quality
	**Performance** • Fun to drive	➢ **Mixed-material architectures - right material right place** ➢ Advanced high strength materials
	**Capability** • Reliability and durability	➢ **Manage corrosion and durability** ➢ Develop and implement design guidelines
	**Sustainability** • Economic plus environmental	➢ CO_2 impact ➢ Recyclability ➢ **Cost of production**
	**Supply** • Global availability, global production	➢ **Equivalencies of local materials on global scale** ➢ Supply route approvals

FMA can help to…

- Define test programmes for materials approval
- Inform materials selection processes
- Mitigate potential failures modes
- Highlight areas for improvement
- Identify key characteristics to control

A Quality Approach to Materials Selection and Development
Acknowledgements

- Thank you to:
  - Helen Dugdale
  - Matt Walters
  - Ian Cross
  - Mike Lough

THANK YOU

Robert Best
Project Engineer – BIW Materials

M +44(0)7469 038 422

robert.best@jaguarlandrover.com

Jaguar Land Rover
W/1/26 Abbey Road, Whitley
Coventry CV3 4LF, UK

jaguarlandrover.com