NMIS
National Manufacturing Institute Scotland

Advanced Forming Research Centre
University of Strathclyde

World leading equipment and expertise at the AFRC

afrc.org.uk

World leading equipment and expertise

The University of Strathclyde's Advanced Forming Research Centre (AFRC) is a specialist technology centre within the National Manufacturing Institute Scotland.

A globally recognised centre of excellence in innovative manufacturing technologies, we have been proudly at the heart of Scottish manufacturing research for over a decade and exist to help manufacturing firms derisk innovation so they can seize new opportunities, access new markets and disrupt existing ones.

Filling the space between fundamental academic research and industry, we provide access to cutting-edge R&D facilities and talented engineers, researchers and business professionals, who are securing the manufacturing sector in Scotland and the UK for generations to come.

Unlock opportunities and access new markets

Research and development is critical to boosting innovation. As a result, we are constantly developing our capabilities; it is how we help businesses like yours improve their products and processes allowing you to better compete.

From solving the toughest manufacturing challenges, to exploring the benefits of digital technologies or navigating the early days of new product introduction, we help you take a step back from your day-to-day operations and provide a fresh perspective.

Along with our expertise, you will benefit from access to our cutting edge facilities. Located near Glasgow Airport, we are home to the latest in manufacturing technology along with a visualisation suite and materials, residual stress, mechanical testing and metrology laboratories, all within 5,680m2 of dedicated research space.

Making the next generation of products

Read on to learn more about the technical capabilities within the centre. These have been selected as a direct response to today's manufacturing challenges and are intended to help companies from across the supply chain make the next generation of products in an increasingly competitive and environmentally conscious world.

Contents

Proudly at the heart of Scottish manufacturing research for over a decade, we exist to help manufacturing firms derisk innovation allowing them to seize new opportunities, access new markets and disrupt existing ones.

Near net shape manufacture

We are pushing the limits of advanced manufacturing. Key to this is helping the companies we work with make better decisions about current and future products to ensure that they are manufactured using material and energy efficient processes.

Ranging from the latest in additive manufacturing to advances in cold forming, our combination of world class technical and design expertise brings real cost and sustainability benefits.

For some manufacturers these benefits could be using a cold process, such as hydroforming, to save up to 70% on tooling costs, for others it might be using additive manufacturing, allowing the production of complex lightweight parts that were previously impossible to realise.

Key expertise:

Additive manufacturing

Additive manufacturing is a transformative approach to manufacturing, resulting in complex geometries without limitations. It allows the companies we work with to make lighter parts that would be impossible to produce by other means. We use it for manufacturing parts, tooling and prototypes, saving on materials, time and costs. Our bespoke Hybrid Laser Metal Deposition (LMD) platform, the first of its kind in Scotland, blends machining and additive in one retrofitted CNC machine and is used across remanufacturing, die repair and gear repair projects.

Incremental near net shape forming and forging

Incremental processes provide an energy and materials efficient alternative to those requiring significant force and heat. Producing parts incrementally and in a cold state negates the need for large-scale equipment and high energy use, resulting in large cost savings for our customers. It also achieves a significant level of shape change in one quick operation. Using the vertical flow former, for example, we can produce very complex shapes made from flat plate in a two or three minutes cycle time.

Machining

Innovative machining strategies can cut production time. Used in combination with other technologies, such as additive manufacturing, they can also deliver enhanced efficiency and sustainability. Recent machining projects include a collaboration with our materials team on distortion prediction for an aluminium aircraft component, and development of near net flow formed components.

Superplastic forming (SPF)

SPF allows the creation of unique and complex products, such as stiff lightweight structures boasting excellent materials properties. Our full-scale SPF delivers impact for industrial customers. Exceptional mechanical testing and process-modelling capabilities enable projects that save the companies that we work with time, materials and money. Lubrication and coatings expertise means improved die life. Replicating process conditions on a small scale allows us to draw conclusions from lab scale tests. We are also focused on addressing SPF's high energy use, driving more efficient ways to achieve the same results.

Cold forming

We're using cold forming in new ways, opening up production of precision components in advanced materials, such as high strength steels. Our focus is on using low energy processes, making them suitable for the next generation of products, such as body panels in electric vehicles, which must be light but strong. Specialisms include forming industrial components, resulting in savings through reduced materials waste and forming lead time. We also assess alternative methods of manufacture, offer finite element modelling, experimental work on state of the art forming equipment and research on lubricants and coatings.

Dies, tools, moulds, design

Tooling forms a huge part of manufacturing costs when using any metal forming or casting process, and even when using plastics or composites. We are helping mitigate this significant investment for industry.

Our machining expertise allows us to cut tools quicker and more effectively. Using additive manufacturing, we can reuse and repurpose tools that have reached the end of their life or require design revisions. Our knowledge across areas such as incremental technologies and design for manufacture allow us to support industry at large scale, also helping firms address specific tooling challenges.

Design and make of lightweight structures

The majority of a product's manufacturing costs are locked in during the design phase when its geometry, materials and specifications are set. Embracing full design flexibility early on allows our manufacturers to make informed decisions about the implications of these decisions. Thinking about combinations of materials, manufacturing processes and functionality at the outset provides the best product with the lowest costs and environmental impact. This flexibility is also important if, later on, the goal is to take the weight out of a product and reap the benefits of manufacturing improvement.

Key kit:

- Hybrid Laser Metal Deposition (LMD) platform
- DMG MORI CTX beta 2000 TC
- WF STR 600 3/6 Horizontal Flow Former
- GFM Radial Forge SKK10R
- ACB 1,200T Superplastic Forming Press
- Jean Perrot Maneo 105/30 Press Brake

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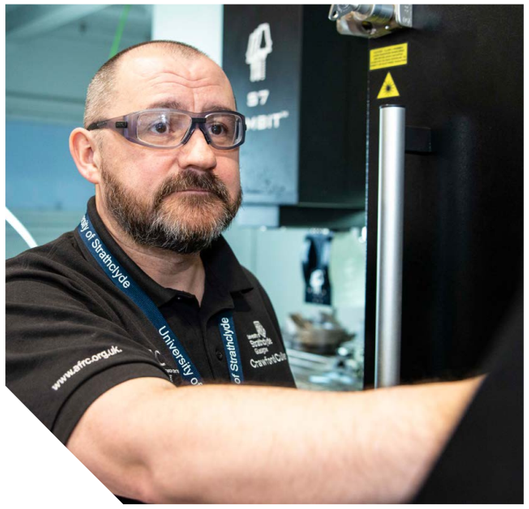
Near net shape manufacture

Additive manufacturing

Laser metal deposition (LMD) hybrid platform

Technical info:
Delivers machining and additive manufacturing in one. A retrofitted three-axis mill machine, it provides additive capability through laser metal deposition (LMD). The laser cladding head adds features to components using LMD; the platform can then revert to traditional tooling. Ideal for remanufacturing projects, die repair and gear repair. LMD materials used include 316 stainless steel, 625 and 718 inconel and stellite 21 and 6.

- Work area: x 2000 mm y 1000 mm z 600 mm
- 1.5 kW fibre laser
- 1 mm and 2 mm spot diameter heads
- Max spindle speed: 15,000 rpm
- Nikken rotary and tilt unit with tailstock allowing shaft work



Wire arc additive manufacturing (WAAM) using plasma arc welding (PAW)

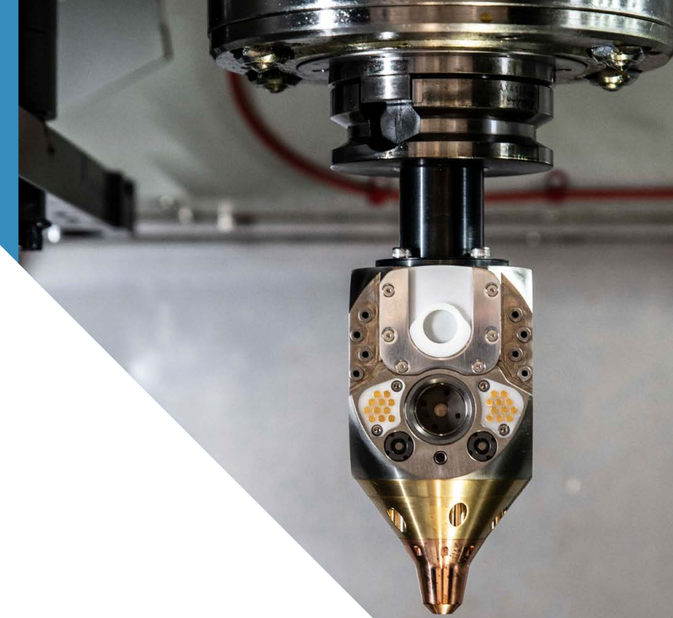
Technical info:
An additive manufacturing robotic cell designed for rapid prototyping of large scale components for safety critical industries such as oil and gas and aerospace, this can also be used for remanufacturing and feature additions. Composed of two 6-axis KUKA robots and non-destructive apparatus, this cell permits dynamic metal deposition using materials such as titanium, aluminium and steel coupled with in-process ultrasonic assessment of components, layer-by-layer. Providing increased efficiency compared to many traditional manufacturing methods, it makes near net shape components with a super accurate surface.

- Two 6-axis 3.1 m reach KUKA Robots
- Ultrasonic probe designed for in process inspection
- CCTV and Xiris XVC-1000e cameras for better monitoring during deposition
- 2 x 1.5 m fixture for flexible component sizes
- Universal 3 Jaw ROTA-S plus 2.0 manual chuck
- Pre-heating 50KVA 6 Channel resistance equipment
- DKP 400 (2 axis) and KP1-MDC2000 (1 axis) positioners
- Portable Arc Monitoring System AMV 3500
- Tetrix 552 Plasma DC

Wire arc additive manufacturing (WAAM) using gas metal arc welding (GMAW)

Technical info:
Similar to our Plasma Arc Welding WAAM robotic cell but on a smaller scale. This comprises of one 6-axis KUKA robot and a 2 axis positioner inside a unique enclosed chamber, which provides controlled atmospheric conditions allowing us to print a wide range of reactive and exotic materials, such as steels, stainless steel, super duplex and nickel alloys. Additionally, its Gas Metal Arc Welding process permits higher productivity while also generating near net-shape components.

- One 6-axis 1.6 m reach Kuka Robot
- CCTV and Xiris XVC-1000e cameras for better monitoring during deposition
- Universal 3 Jaw ROTA-S plus 2.0 manual chuck
- Pre-heating 50KVA 6 Channel resistance equipment
- DKP 400 (2 axis) positioner
- Portable Arc Monitoring System AMV 4000
- TPS Digitech/Robocase 5000 VP2 Power source, 400V



Markforged MKii

Technical info:
Used for advanced prototyping and fixtures. The creation of a physical 1:1 or scale prototype enables our researchers and engineers to assess products and components before committing to production.

- Min layer resolution: 100 microns
- Max layer resolution: 200 microns
- Minimum feature size: 0.8 mm
- Build volume: 296 mm x 195 mm x 165 mm

MakerBot Replicator +

Technical info:
Primarily used for early stage prototyping. Models and prototypes are used in conjunction with digital models, enabling greater understanding of final products. The models can also be used to assess ergonomic fit, for example, handles and grips etc.

- Build volume: 320 mm x 132 mm x 154 mm
- Min layer resolution: 100 microns
- Max layer resolution: 300 microns

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Near net shape manufacture

Additive manufacturing

Stratasys Fortus 900mc

Technical info:
A remarkably agile, accurate machine, the Stratasys Fortus 900mc 3d printer delivers a high return on investment thanks to its faster manufacturing and materials savings capabilities. One of the most advanced machines on the market in terms of speed and size, the FDM 3D Printer takes 3D printing to a new level of manufacturing.

The Fortus 900mc is built specifically for manufacturing and heavy industries, where you plan and work big. The 900mc builds in 14 strong thermoplastics for applications that require bio-compatibility, high performance or resistance to heat, chemicals or UV radiation.

- Build size: 914.4 x 609.6 x 914.4 mm
- Layer thickness: 0.127 - 0.508 mm
- Choice of 14 thermoplastic materials including ULTEM and carbon filled nylon
- Suitable for jig and fixtures
- Suitable for production parts and tooling and robot end effectors
- Capable of manufacturing aerospace grade production parts

Stratasys J850

Technical info:
Whether you need to create an early stage prototype or a high fidelity model, our J8 3D printer is designed for all stages of design and applications and, can produce 5 times more design iterations than traditional methods allowing you to accelerate the pace in which you can create models.
Create a multitude of textures including simulated leather, soft touch materials, and woodgrain among others. Rigid, flexible, transparent or opaque, our multi-material capacity means you can load up to seven materials at once whilst the expansive colour and texture combinations remove the need for model painting.

In addition, our two support material options dissolve easily, giving you the freedom to print complex and delicate features, without the hassle of laborious post-processing.

- Build size: 490 x 390 x 200 mm
- Layer thickness: 14 microns
- Early stage prototypes
- High fidelity models (experienced prototypes)
- Dissolvable support strucures

Near net shape manufacture

Machining

DMG MORI HSC 75 linear

Technical info:
DMG Mori's premier manufacturing machine tools are used across industry. This machine offers linear drives in all axes meaning increased speed, accuracy and accelerations, which provide the perfect conditions for machining die and mould applications. Used for the development of tools, die and moulds manufacture and to investigate machinability and optimisation strategies.

Work area
- X-axis travel: 885 mm
- Y-axis travel: 600 mm
- Z-axis travel: 600 mm
- Tool magazine: 60 pockets
- Transverse rate: 90 m/min.

Main drive
- Max. spindle rating: 43.5 kW
- Max. spindle speed: 28,000 rpm
- Max. cutting diameter: 750 mm
- Control: DMG Ergoline Control 840D
- 28,000 rpm motor spindle for powerful roughing and high speed cutting
- Renishaw probing, with MSP NC Perfect Part, for machine set up and part verification

DMG MORI DMU 125 FD duoBLOCK

Technical info:
With turning and milling in one set up, this allows for complete machining in a single operation for maximum productivity. A turning capacity of 1.2m means we use it for machining larger components. Used across projects, such as distortion prediction on an aluminium aircraft structural component, and cutting trials for oil and gas industry clients.

Work area
- X-axis travel: 1,250 mm
- Y-axis travel: 1,250 mm
- Z-axis travel: 1,000 mm

Table
- Milling/turning table: 20/500 rpm
- Max. table load: 2,000 kg

Main drive
- Max. spindle speed (milling): 12,000 rpm
- Max. spindle speed (turning): 500 rpm
- Max. cutting diameter: 1,250 mm
- Control: Siemens 840D solutionline
- Milling and turning in one setup with the DirectDrive table and rotational speeds up to 500 rpm
- Renishaw probing, with MSP NC Perfect Part, for machine set up and part verification

DMG MORI NLX 2500 | 700

Technical info:
Widely used at the centre, this offers turning and milling in one. It can handle various types of workpieces, from simple to complex shaped components. A sub spindle means that it is highly efficient, and it offers live tooling, which enhances efficiency even further.

Work area
- X-axis travel: 260 mm
- Y-axis travel: ± 50 mm
- Z-axis travel: 795 mm

Main drive
- Twin spindle speed: 4,000 rpm
- Control: CELOS with ERGOline and MAPPS
- Renishaw probing, with MSP NC Perfect Part, for machine set up and part verification

Breton Raptor

Technical info:
A 5-axis machining centre that is designed for machining complex, large scale, 3-D components for the aerospace industry. Rigidity and high dynamics are distinctive features of this range making it ideal for machining a multitude of components and products at high speeds with maximum milling performance.

- Speed of linear axes: up to 80 m/min
- Rotation of axis C: ± 200˚
- Rotation of axis A: 0˚ to +115˚
- Working area: up to X 4,000 Y 3,000 Z 1,200 mm

Matsuura MX520

Technical info:
A compact 5-axis vertical machining centre featuring an outstanding ergonomic design, which allows rapid set-up and processing of complex parts. CAMplete TruePath software – an integrated suite of G-code editing, optimization, analysis, and verification tools are standard.

- Table working surface:11.81 in
- Max. Work Size: 20.47 x H13.77 in
- Spindle Speed Range: 40 -12,000 min-1 (20,000 min-1)
- X-axis travel: 24.80 in
- Y-axis travel: 22.04 in
- Z-axis travel: 20.07 in

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Near net shape manufacture

Machining workshop

AgieCharmilles wire EDM F1440CCS

Technical info:
A versatile machine that can cut 45˚ cones whatever the height of the part. It is widely used at the centre and is ideal for machining complex components. Also used across industry to manufacture high-precision complex parts.

AgieCharmilles hole drill 11

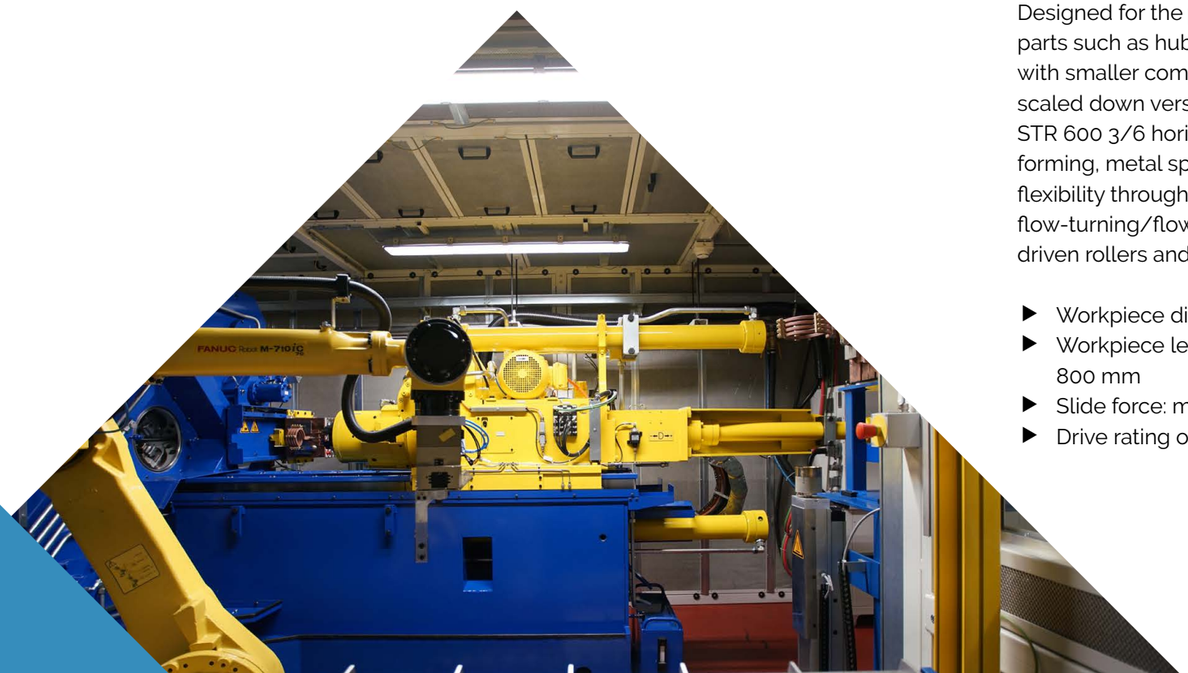
Technical info:
The high-speed DRILL 11 offers multiple point EDM hole drilling capabilities and an integrated rotation spindle, which allows for automated erosion of holes at multiple locations with minimal intervention.

Haas TM-2 CNC toolroom mill

Technical info:
The TM-2 is a versatile machine that combines the functionality and simplicity of a manual mill with the power and flexibility of the Haas CNC control, making it ideal for tool rooms and shops transitioning to CNC.

Haas TL-1 CNC toolroom lathe

Technical info:
Equipped with the Haas Intuitive Programming System, the TL-1 is extremely easy to learn and operate. Operations that would be difficult on a manual machine, such as compound angles, radii, tapers, ID and rigid tapping.



Near net shape manufacture

Incremental near net shape forming and forging

MJC rotary forge – RFN-200T-4

Technical info:
Custom built by MJC, this is a unique spin - nutation rotary forge. A nutation angle range of 0-45 degrees allows forming of flanged components from hollow tubular work-pieces, meaning less materials wastage and no joining methods required. Using this process, up to 90% material savings can be achieved compared to conventional machining from a solid blank.

- Workpiece diameter range: 50 – 450 mm
- Spindle speed: 20-200 rpm
- Slide stroke: 800 mm
- Max force: 1960 kN

WF VUD600 vertical flow former

Technical info:
Designed for the production of complex cylindrical parts such as hubs, gear shafts and pulleys along with smaller components with features. Forms scaled down versions of items formed on WF STR 600 3/6 horizontal flow former. Used for flow forming, metal spinning and shear forming. Provides flexibility through two independently controllable flow-turning/flow-forming slides, with hydraulically driven rollers and hot working capability.

- Workpiece diameter: 15 mm – 600 mm
- Workpiece length forward flow forming: max. 800 mm
- Slide force: max 250 kN
- Drive rating of main spindle: 200 kW

WF STR 600 3/6 horizontal flow former

Technical info:
One of our most widely used machines, its capabilities include flow forming, metal spinning and shear forming. Ideal for producing high quality thin walled products that are difficult to manufacture using traditional methods, such as machining. Also possible to form select materials in their hardened conditions. Typically used in sectors such as aerospace engineering, power and environmental.

- Workpiece diameter range: 60-600 mm
- Workpiece length; forward flow forming: max. 2,200 mm
- Workpiece length; reverse flow forming: max 4,000 mm
- Spindle speed: 120–240 / 240–420 / 420–700 rpm
- Slide stroke: max force: Radial force 350 kN/axial force 500 kN

GFM radial forge SKK10R

Technical info:
A fully automated four-hammer machine with integrated induction heating capabilities. Used for trialling and proving the manufacturing route for many applications, including automotive transmissions and aerospace components. Also ideal for forging titanium, nickel alloys and steels in a hot, cold or warm condition.

- Max. forging force: 1,500 kN
- Max. starting dia blank: 120 mm
- Min. dia: 20 mm
- Min. length of blank: 70 mm
- Max. length of forged part: 950 mm
- Max. workpiece weight: 25-30 kg

Near net shape manufacture

Superplastic forming

ACB 200T superplastic forming press

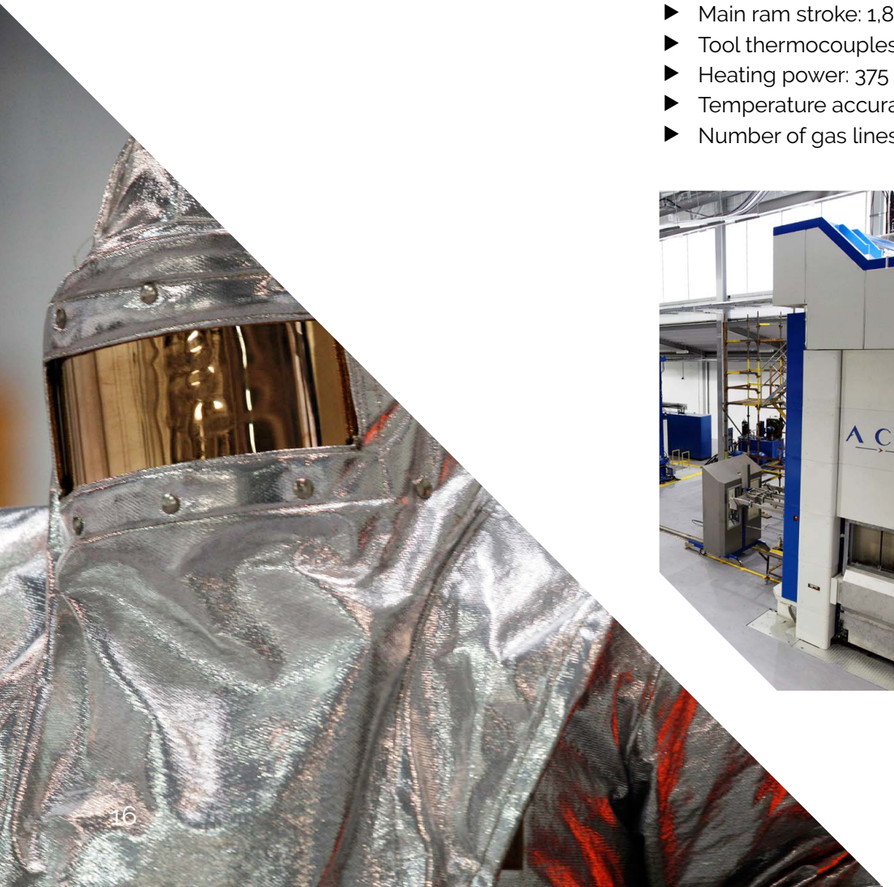
Technical info:
Supports forming of mid-sized single and multi-sheet structures, with design features representative of production parts, to validate finite element modelling studies and optimal forming curves through experimental trials.

- Static force: from 200 kN to 2000 kN
- Platen dimensions: 760 x 760 mm
- Max daylight: 700 mm
- Main ram stroke: 500 mm
- Tool thermocouples: 6

ACB 1,200T superplastic forming press/ 600T hot creep forming press

Technical info:
A globally unique research press based on its size and capability. This 1200 tonne superplastic forming press is used for the production of larger industrial-size geometries, such as full-scale aerospace components, providing a unique capability for a research environment. Offers creep forming capabilities up to 600 tonne.

- Static force: 500 kN to 12,000 kN
- Heating platens: 2,400 x 2,000 mm
- Max. daylight: 2,000 mm
- Main ram stroke: 1,800 mm
- Tool thermocouples: 12
- Heating power: 375 kW
- Temperature accuracy: 950˚ C ± 10˚ C
- Number of gas lines: 3



Our focus is on using low energy processes, making them suitable for the next generation of products, such as body panels in electric vehicles, which must be lightweight and strong.

Near net shape manufacture

Cold forming

Jean Perrot Maneo 105/30 press brake

Technical info:
Used for achieving complex bending patterns of sheet and plate metals. Supports springback measurement and formability assessment of metal sheet and plate. External preheat from a furnace or infrared heating used for semi-coining and warm bending. Bending a wide range of materials, including complex alloys and aerospace and automotive grades, we also use it to create complex 3D shapes.

- 1000 kN CNC press-brake
- 3m horizontal bend length
- Automatic bend correction capability
- Lower tool hydraulic clamping system
- Opposing wave technology crowning system
- Maximum stroke 250 mm
- 6 axis powered CNC back-gauge (X1, X2, Z1, Z2, R1 & R2)

Hydroforming

Technical info:
Hydroforming is an established manufacturing process but we're finding new ways to exploit its benefits, using harder to deform materials and exploring increasingly complex geometries. It can provide a reduction in tooling costs of up to 70% compared to traditional stamping tooling. Also enables the forming of complex shapes, which reduces welding and assembly requirements.

Benefits of hydroforming:
- 50% less tooling
- Tooling costs up to 70% cheaper than traditional stamping tooling
- Reduced welding requirements for complex shapes
- Enhanced opportunities for light weighting

Near net shape manufacture

Cold forming

Incremental sheet forming

Technical info:
Cost effective and accessible, we use it to manufacture small batch products or prototypes. In a successful project with Boeing and TIMET we focused on complex shaped parts, exploring how cold forming techniques could offer cost reductions. We demonstrated that manufacturing using this technology helps shorten time to market, reduce development costs, shrink production cost and energy usage, and obtain desirable parts in a small series.

Deep drawing

Technical info:
Offering significant experience in deep drawing, we have developed a complex FE model of the deep drawing process, helping to reduce the number of physical trials required across customer projects, also enabling quick forecasting of optimum parameters. Exploring the forming of lightweight materials, such as titanium, the team is also using press forming (room temperature and up to 400˚C), which is another fast rate and cost effective manufacturing technology.

Automated die wear rig

Technical info:
Custom-built instrument that simulates tool-workpiece contacts under extreme conditions, enabling real-world applicable conclusions to be drawn from laboratory-scale tests. Fully automated part loading and unloading replicates uninterrupted 24/7 production schedules. Originally designed to model a specific superplastic forming process, die wear has since been successfully evaluated for a range of process conditions and work piece alloys. Key projects include investigations into lubricants, wear resistant coatings, low cost metallic dies and ceramic dies.

- Retractable furnace for part heating up to 1000˚C
- Variable stack load: 0 – 19.25 kN
- Upper die can be rotated to simulate sliding contact conditions
- Thermocouple attachment points allow for continuous monitoring of furnace, stack and die temperature changes
- Modular construction allows trials of varying part geometries, materials and coatings
- Thermal camera captures in situ die conditions

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Material behaviour

We are shining a light on materials science and residual stress within manufacturing – with significant benefits for industry.

By understanding the different effects of manufacturing processes on components we can increasingly employ a predictive approach, which boosts efficiency and saves time and money during costly trials. Materials characterisation expertise also helps the manufacturers we work with make better decisions and overcome production problems.

Measurement of residual stress is a key priority at the AFRC because it drives product life and integrity, as well as influencing manufacturing cost. Our state of the art laboratory for residual stress evaluation and strain mapping, the only one of its kind in Scotland, is where the materials magic happens.

One of the very few labs across the UK that is ISO 17025 accredited for relevant measurement techniques, we provide far more than purely testing, offering a range of solutions, industrial expertise and materials intelligence.

Key expertise:

Advanced material characterisation

Describing how materials behave under certain conditions enhances our understanding and modelling capability, allowing us to be genuinely predictive. We benefit from a full suite of characterisation equipment, chosen for its ability to replicate strain rates, deformation rates and temperatures across full-scale industrial forging and forming equipment. The jewel in the crown is our bespoke Phoenix testing machine, which is a unique high performance forge simulator. We employ a holistic approach to materials characterisation, encompassing modelling and prediction, processing, testing and validation, all under one roof.

Residual stress measurement, modelling and management

Residual stress is a common, but often unidentified, side effect of many manufacturing processes. This locked in energy can lead to unexpected consequences, such as the early failure of a part or distortion out of required tolerances. It can also be favourable and harnessed to stop materials from cracking or to extend the life of a product. As one of the top teams in the world for evaluating, understanding and managing residual stress within manufacturing, we bring numerous benefits to the businesses we work with including materials savings, enhanced efficiency, barriers to competition and a deeper understanding of their products and processes.

Key kit:

- PRISM hole-drilling based on Electronic Speckle Pattern Interferometry (ESPI)
- MTS-3000 hole-drilling system based on strain gauge rosette
- Instron Electro-Thermal Mechanical Testing (ETMT)
- Phoenix High Strain Rate Testing Machine (up to strain rate of 300 per second)
- FEI Quanta 650 FEG scanning electron microscope (SEM)
- PROTO LXRD modular mapping system

Material behaviour

Advanced material characterisation

Zwick / Roell Z250 Amsler material testing machine

Technical info:
Examines the mechanical behaviour of materials under compression, tensile and cyclic loading conditions. Ideal for measuring the material properties of flow formed parts. Provides enhanced control but less maximum strain than hydraulic driven machines. Allows high temperature testing of materials and uses bespoke software for complex testing modes involving rapid changes to the strain rate.

- Load capacity: 250 kN
- Temperature capacity: 1,500˚C
- Strain rates: 10-5s-1 to 0.1s-1
- Mechanically driven test frame
- Contact / non-contact extensometry

Zwick / Roell Z150 material testing machine

Technical info:
Like the above but with less maximum strain, this features an MTS extensometer and GOM® Aramis for deriving the plastic strain ratio (r) value. Can be used for strain rate jump testing, stress relaxation testing and controlled in either a positional, load-controlled or true strain rate mode.

- Load capacity: 150 kN
- Temperature capacity: 1,400˚C
- Low strain rates: 10-5s-1 to 0.5s-1

Zwick / Roell HA 250 Servohydraulic testing machine

Technical info:
Used to study the mechanical behaviour of materials under compression, tensile and cyclic loading conditions. A hydraulic drive, as opposed to screw, allows for higher strain rates and larger loads. Primarily used for testing at higher strain rates than those covered by the Z250 and typically supports material characterisation programmes linked to the simulation of forging process.

- Load capacity: 250 kN
- Max. temperature: 1,250˚C
- Max. height of test frame: 3,040 mm
- Strain rates: 0.1s-1 to 3s-1
- Displacement rates of up to 150 mm per second

Instron electro-thermal mechanical tester

Technical info:
Developed by the AFRC and National Physical Laboratory (NPL) for testing metals and other conductive materials. Ideal for micro type samples we don't want to destroy through mechanical testing. Also useful for creating a full tensile test from a small sample. Can achieve high fatigue loading rates and very rapid rates of heating and cooling.

- Load capacity: 5 kN
- Resistance heating: 400 amps
- Environmental chamber (vacuum, protective atmosphere)

Phoenix high strain rate testing machine

Technical info:
For conducting experiments in the range of, 'medium', strain rates in compression, up to a maximum of 200s-1, at high temperatures up to 1,150˚C. Ideal for detailed simulation of thermo-mechanical conditions taking place during hot forging in screw presses and hammers. Supports study and prediction of the mechanical behaviour of alloys under forging conditions by providing data for use in modelling and simulation.

- Maximum testing load: 600 kN
- Max. speed: 3.6 m/s
- Speed control: +/- 5%
- Temperature capability: 1,150˚C (material dependent)

FEI Quanta 250 FEG SEM

Technical info:
Used for structural and chemical analysis of metallographic specimens, this offers high flexibility to increase performance and versatility. It can achieve magnification of up to 1,000,000x, providing high resolution image in a digital format. Also operates at low vacuum, enabling the imaging of non-conductive samples. Designed to provide maximum data- imaging and microanalysis from all specimens, with or without preparation.

- Magnification: 14 x to 1,000,000 x
- Max. electron beam resolution: 3 nm at 1kV

FEI Quanta 650 FEG

Technical info:
Similar to the above, used for structural and chemical analysis of metallographic specimens.

- Magnification: 6 x to 1,000,000 x
- Max. electron beam resolution: 3 nm at 1kV

Kammrath Weiss micro thermo-mechanical sub-stage

Technical info:
Used inside a scanning electron microscope (SEM) allowing in situ studies for examining materials at grain level. Can be used as an integrated system within the SEM, fitted inside the electron microscope chamber (max. temperature 1200˚C), or as a 'bench top,' micro thermo-mechanical tester in the laboratory (max. temperature 200˚C). Operates in tension, cyclic tension-compression, and 4-point bend test modes.

- Load capacity: 5 kN
- Max. temperature: 1,200˚C

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Material behaviour

Advanced material characterisation

GOM Aramis 3D motion and deformation sensor

Technical info:
A non-contact and material-independent measuring system based on digital image correlation. Performs high-precision measurements independently from geometry and temperature without time-consuming and expensive preparation. Provides 3D surface coordinates, 3D displacements and velocities, surface strain values and strain rates. Used for determination of materials properties, component analysis, and verification of FEA and real-time control of testing devices.

- Camera resolution: 2,448 x 2,050 px
- Frame rate: 15 Hz up to 29 Hz
- Camera resol. 2,448 x 2,050 px

LaVision digital image correlation (DIC) system

Technical info:
A key piece of equipment used by our materials team. Often used alongside our Instron Electro-Thermal Mechanical Tester and Zwick machines to create strain maps, which provide a comprehensive picture of material properties. A powerful piece of equipment that is particularly useful for complex and small parts, allowing for the attachment of a gauge when necessary.

- Displacement resolution: 0.01 pixel
- 2D and 3D displacement mapping
- Captures images at high strain rate tests such as compression tests at 5m/s speed or up to 200 1/s true strain rates

Zwick / Roell BUP 1000 sheet forming machine

Technical info:
Widely used here at the AFRC but rare out in the field, this hydraulically operated testing machine is used to study the room temperature formability of sheet materials. Conducts techniques and tests such as Nakajima test, Marciniak test, Ericsson test, earing test and cupping test. The machine's low piston-cylinder friction enables accurate measurement recording and excellent reproducibility.

- Max. test load: 1,000 kN
- Max. ram stroke: 150 mm
- Max. deep drawing speed: 750 mm/min
- Max. sample size: 260 mm wide

Olympus GX51 inverted metallurgical microscopes

Technical info:
Used for optical analysis of metallographic specimens and is equipped for brightfield, darkfield, DIC and simple polarisation observations.

Leica DM12000 M optical microscope

Technical info:
Used for optical analysis of metallographic specimens, this offers macro magnification that gives four times the field of view of conventional scanning objectives.

Material behaviour

Residual stress measurement

The AFRC's residual stress measurement and strain mapping lab enables us to measure surface, sub-surface and bulk residual stresses using the following techniques:

- X-Ray Diffraction (XRD)
- Incremental Central Hole Drilling (ICHD)
  1. ICHD based on Strain Gauge Rosette
  2. ICHD based on Electronic Speckle Pattern Interferometry (ESPI)
- Contour Method
- Slitting Method
- Digital Image Correlation (DIC) for displacement and strain mapping

PROTO LXRD modular mapping system

Technical info:
A high-powered residual stress mapping machine used to measure large components and work hardened metals. Over two meters of measurement space, heavy-duty XY mapping stages, and a removable mapping stage. Provides flexibility to meet all complex measurement needs and measures surface residual stress in a range of materials including Ti alloys, Ni alloys, Al alloys, steel and stainless steel.

Restan MTS-3000 hole drilling system

Technical info:
A conventional hole drilling system used for automatic step-by-step drilling and strain measurement with a controllable feed rate. Fully automatic process and automatic drilling, its user can select a number of drilling steps, profiles and feed rates. Offers high repeatability and high speed drilling, providing high measuring accuracy.

- Max. turbine speed: 400,000 RPM
- Max. turbine feed pressure: 5 bar
- Drilling resolution: 5 µm
- Drilling speed range: 0.03 – 1 mm/min

Electronic speckle pattern interferometry (ESPI)

Technical info:
Measures residual stresses by drilling a narrow hole into a component and using a laser light source and video recording equipment to measure distortions. This type of testing is semi-destructive and benefits from requiring little surface preparation before measuring. It provides measurements of near-surface residual stresses from distances as close as 10µm from the surface.

- Max. turbine speed: 50,000 RPM
- Max. turbine feed pressure: 5 bar
- Drilling resolution: 5 µm
- Drilling speed range: 0.001 – 0.4 mm/sec

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Material behaviour

Residual stress measurement

Contour method

Technical info:
Ideal test for analysing full field measurements. Used to determine residual stresses at any depth while handling changes in microstructure without reducing reliability of results. A fully destructive test, it can also be difficult to apply to complex geometries. Determines residual stress through cutting and measuring surface height maps, or contours, on the free surfaces created by the cut.

Slitting method

Technical info:
Involves cutting a slit across a component, typically using wire-EDM, and measuring the surface strains with strain gauges located underneath or next to the slit. A destructive mechanical strain release (MSR) technique that can accurately measure both near surface and through thickness residual stresses.

Digital Image Correlation (DIC) for strain and displacement mapping

Technical info:
Allows us to determine surface displacement due to the material deformation via consecutive optical observations. It numerically analyses a digitised intensity image of an object in the deformed state and cross correlates it with the same object in the original image to determine the displacements between the two images.

- Measures in 2D and 3D
- Measures from micro-macro scales

UltraMars ultrasonic system

Technical info:
A non-destructive residual stress measurement technique. It offers the capability of measuring surface, subsurface and bulk residual stresses. This is achieved by using differently angled transducers to send and receive the ultrasound. This system is in continuous development.

- Stress can be measured in materials with thickness 2 - 150 mm
- Error of stress determination (from external load): 5 - 10 MPa

Materials preparation

- Buehler VibroMet 2 Vibratory Polisher
- Buehler EcoMet 300 Grinder Polisher
- Struers LectroPol-5 Electrolytic Polishing Machine
- Buehler Abrasimatic 300 Abrasive Cutter

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Data driven manufacturing

We are reimagining the factories of the future, today. Industry 4.0 is here and that means faster computers, increased connectivity, greater storage and an evolution in sensing and artificial intelligence.

Combined with new manufacturing technology, this brings enormous opportunity for improvement; with everything connected and data extraction available across all stages of manufacture, we work with companies like yours to enhance the efficiency of machinery on the shop floor along with back office and supply chain management.

Making decisions based on data can also be used beyond day-to-day operations, enhancing our understanding of traditional 'black art,' manufacturing processes so that we can better predict and control them.

Key expertise:

Measurement and sensing

The drive towards digitalisation is as much about extracting the data as it is about the technologies used to interpret and reveal it. This involves taking measurements, or sensing, the information from machines. Typically thought of as an end of line process for verification, measuring and sensing is used throughout a process, alerting operators as to whether they are in control and regularly feeding back key data. Our expertise in this area is vast, extending from challenging metrology to photogrammetry, validating existing measurement systems, and integrating measurement with automation.

Connectivity

The advent of 5G will enable connected everything. Connecting shop floors, machines and back office work environments can bring significant business and supply chain improvements, but within a manufacturing environment considering all factors, such as cybersecurity, is crucial. We help manufacturers embrace connectivity by capturing and interpreting real time data from their manufacturing systems to boost uptime, production quality, security and energy efficiency. Along with deploying sensors on legacy systems and integrating them at PLC level, we are also developing machine-to-machine communication and machine learning.

Visualisation

Visualising the data that industry 4.0 brings with it is key. Augmented reality provides data in 3D so that operators and users can interpret the information and make quick decisions based on facts and the best predictive technology available.

Using our state of the art visualisation suite, we help businesses of all sizes embrace technology to improve their facilities and production processes. Working on fully immersive virtual and augmented reality, we allow firms to test different scenarios including training, use of space, changes to the production line and implementing new equipment.

Automation

Hot harsh manufacturing environments are challenging to automate but we can help you on this journey. Automation does not only provide benefits on the shop floor, taking the danger or time out of repetitive tasks; it can also be used for back office work for automating high value adding activity, which releases highly skilled people to focus on more creative work. Our research spans manufacturing robotics and fixed asset inspection.

Key kit:

- State-of-the-art digital visualisation suite
- Mitutoyo CMM Crysta Apex C
- Hexagon Manufacturing Intelligence Absolute Arm
- 3 x KUKA KR90 High Accuracy Extra Robots

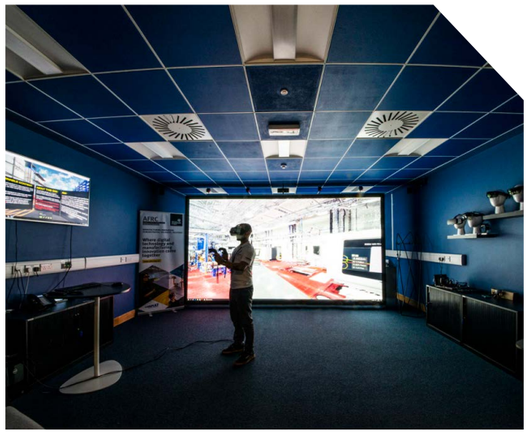
Data driven manufacturing

Visualisation

State-of-the-art digital visualisation suite

Technical info:

Our state-of-the-art digital visualisation suite provides a unique set of capabilities available for commercial research and development work



Interactive 3D visualisation systems

- 10 m2 Virtalis Active Wall
- Virtalis Active Move
- Virtalis Visionary Render

Technical info:

The centrepiece of our digital visualisation suite is the 10 m2 Virtalis Active Wall. A 4K projector is combined with a large frame, screen, a computer, AR emitter/3D glasses in one system. A fixed 3D stereoscopic projection system with head and hand tracking system, allows multiple users to view 3D content.

The suite's extensive kit list includes various virtual reality systems that we add to all the time. Our portable Active Move system is ideal for taking to our customer's industrial premises.

Used for: Fully immersive design reviews, visualisation of complex geometry, immersive virtual training, virtual prototyping environments, virtual collaborative design environments, immersive virtual asset reviews, immersive 4D planning.

Virtual reality systems:

- HTC Vive
- Oculus Rift & Touch
- Samsung Gear VR
- Google Cardboard
- Windows mixed reality headset
- Leap Motion controller
- Meta 2
- FOVE 0 eye tracking

Data driven manufacturing

Measurement and sensing

GOM ATOS 3D scanning

Technical info:

Captures surface geometry using stereoscopic cameras and structured light projections.
Each of its high quality optical cameras works independently from one another, allowing it to capture accurate 3D scans from different angles. Used for full surface reconstruction capture, reverse engineering for legacy products and before/after scan analysis.

- Camera pixels: 2 x 8,000,000
- Measuring area: 38 mm2 - 2,000 mm2
- Point spacing: 0.02 mm - 0.61 mm
- Measured points per scan: 8 million points

GOM TRITOP optical 3D CMM

Technical info:

Portable digital photogrammetry system designed to quickly and accurately measure the coordinates of 3D objects. Use it as a standalone coordinate measuring system (CMS) for inspection and deformation analysis, plus in conjunction with ATOS to help maintain accuracy over very large or complex areas. Data collected using the TRITOP can be used for CAD model comparison.

- Measuring time per object: 5 - 60 min
- Measuring points per object: 10 - 50,001

GOM PONTOS dynamic 3D analysis

Technical info:

A motion analysis system that accurately determines the 3D coordinates of object points over time. Ideal for measurements that are high rate or require very high accuracy. In contrast to conventional displacement measuring systems, it reduces the measuring procedure to a fraction of the time. Measuring capabilities include 3D coordinates, 3D motion and deformation, 3D velocity, 3D acceleration, 6 degrees of freedom (6DoF) measures.

- 2 high speed cameras
- Max. frame rate: 500 Hz
- Max. resolution: 1,024 x 1,024 px

Mitutoyo CMM Crysta Apex C

Technical info:

A coordinate measuring machine (CMM) that allows for reliable quality control. Built using lightweight materials, this moving-bridge type machine structure provides high motion stability and high accuracy. Capable of measuring most geometries with excellent accuracy. Used for attachment of touch trigger and scanning probes, capturing freeform geometry and conventional 3D coordinate measurement.

- Max. drive speed: 520 mm/s
- Max. acceleration: 0.23 g
- Max. permissible error: +/- (2.3+3L/1,000) µm
- Measuring range: 1,205 x 1,205 x 1,005 mm
- Measuring speed: 1 - 50 mm/s
- ISO 10360 verified and traceable measurement

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Data driven manufacturing

Measurement and sensing

Alicona InfiniteFocus IFM G4 optical 3D micro coordinate system

Technical info:
A 3D micro coordinate measurement machine and surface roughness measurement device combined in one system. The system's coaxial lighting and optimised LED ring light, means the range of measurable surfaces is almost unlimited. Provides repeatable, full high-resolution measurements, including variable and integrated automation options.

- Max. number of measurement points
- X: 540,000
- Y: 540,000
- X x Y: 500 million
- Min. vertical repeatability: 0.12
- Optimal vertical resolution: 10 - 410 nm
- Objective magnification: 5x, 20x, 50x, 100x

Hexagon Manufacturing Intelligence Leica AT960-LR laser tracker

Technical info:
A highly sophisticated yet easy-to-use large-volume scanner for a wide variety of inspection applications. Has an extensive range of up to 160m diameter and 40m with six degrees of freedom orientation - meaning it knows the point in space plus the orientation of the object. Can be coupled with the T-Probe and LAS systems, described below, to create a large volume coordinate measuring machine (CMM) and laser scanner.

- 3D Measurement up to 160 m, 6 DoF up to 40 m
- The specified Maximum Permissible Error (MPE) of the system when measuring a 1.4 m length at a distance of 6.5 m from the tracker is 0.076 mm
- As an Absolute Distance Meter (ADM) the tracker achieves an accuracy of 0.009 mm up to 48 m

Hexagon Manufacturing Intelligence Leica T-Probe III

Technical info:
A 'walk-around' armless wireless device for probing hidden, hard-to-reach points, capturing up to 1,000 points per second. We combine it with the AT960 tracker for previously unfeasible 3D digitisation tasks, such as measurements on large parts, such as cars.

- MPE when measuring a 2.3 m length at a distance of 20 m is specified as 0.197 mm

Hexagon Manufacturing Intelligence LAS & LAS-XL

Technical info:
These are market-leading 3D scanners for producing digital models. We also combine them with the tracker for handheld, easy-to-use portable 3D scans. The XL model is for even bigger scans that have traditionally been challenging, with a standoff distance of 1 m. Offers a greater scanning width and standoff distance and is set up to capture larger geometries quickly.

- Scanning width of the XL is 600 mm with a standoff distance of 1000 mm
- LAS scanning width is 220 mm and standoff distance is 180 mm

Hexagon Manufacturing Intelligence Absolute Arm

Technical info:
The most accurate piece of technology of its type ever produced. A portable articulated arm CMM with contact probes. Features a laser scanner integrated into the pistol grip probe. We use it for taking measurements before a part is removed from a machine to check for distortion. Also used for dies and moulds, tooling, parts, jigs and fixture setup and alignment, tubes and tube assembly, CAD-to-part comparison, alignment, reverse engineering and virtual assembly.

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Data driven manufacturing

Automation

3 x KUKA KR90 high accuracy extra robots

Technical info:
Mounted on 6 meter linear tracks, our three KUKA robots each have a 90kg payload, 3.1 m reach and 0.6 mm accuracy. The reconfigurable cell can hold components up to a length of eight meters and boasts high speed ultrasonic phased array inspection capacity. Used for various projects including non-destructive testing (NDT) of a large scale component, combining high speed robot control with surface metrology and NDT inspection.

- Flexible robot control – Simultaneous 250 Hz motion control of all robots, tracks and rotary axis
- Integrated force/torque control and feedback into robot path at 250 Hz

Fanuc M-710iC robot

Technical info:
We also have robot cells in our workshop, performing activities across pieces of equipment. The M – 701iC robot is a 6-axis robot that can handle a 50kg payload. Mounted to a track to increase mobility and integrated with a forging press, clipping press and a furnace. Used for automating and speeding up the formerly manual process of handling and moving high temperature parts between the press and furnace.

- Max load capacity: 20 kg
- Maximum speed: J1 200˚/sec
- Maximum speed: J6 720 ˚/sec
- Maximum reach: 951 mm
- Repeatability: ± 0.08 mm
- J4 moment: 15.7 Nm
- J5 moment: 9.8 Nm
- J6 moment: 5.9 Nm

Fanuc die wear cell robot

Technical info:
Custom built for our die wear cell, this robot allows for the replication of 24-hour production cycles by continuously loading and unloading metallic test samples.

Combined with new manufacturing technology, this brings enormous opportunity for improvement; with everything connected and data extraction available across all stages of manufacture, we work with businesses like yours to enhance the efficiency of machinery on the shop floor along with back and supply chain management.

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Material processing

We specialise in forging research and will soon install the world's most advanced hot forging platform complete with industry 4.0 ready demonstrator.

Forging is the manufacturing method of choice for high integrity products, such as aerospace discs and pressure vessels, which must be strong, durable and safe. Increasingly, they must also be lightweight and made using more sustainable methods.

As the global forging market continues to grow – it was valued at over $67 million in 2017 and is expected to reach over $107 million by 2024 – our goal is to make forging more predictive and efficient. We are using forging and complementary heating technologies to convert materials so that they are ready for the next generation of products made using stronger, lighter metals for higher temperature applications.

Key expertise:

Open die

The materials designed to be strong and resistant to shape change when a product is in service are, by their nature, also difficult to shape during manufacturing. Open die forging is the process of deforming a piece of metal between multiple dies. We like to think of it like blacksmithing but on a much larger scale. It breaks a material's grain structure to create a fine strong structure, which is essential for high integrity products. Often used for products, such as discs and shafts, we are exploring new ways to use it because of its material benefits. These include increased strength and fatigue resistance gained during deformation due to the repeated working of the steel billet.

Isothermal

The die and the workpiece remain at the same temperature during isothermal forging. A specialist type of forging, it allows the production of net shape components with fewer processing steps. It also opens up the use of super sensitive materials, like intermetallics, which can't be forged by other means. Lightweight and strong, these materials are brittle and difficult to work, but can survive at extremely high temperatures. With the launch of FutureForge, a bespoke 2000 tonne trimodal forging press will facilitate industry scale isothermal forging, allowing us to develop the next generation of alloys, also working to make Isothermal forging more energy efficient and accessible.

Closed die forging

Closed die forging achieves a combination of the best set of material properties and final shaping. Heated raw material, shaped into the final part, is placed in the bottom die while a negative image of the final part is placed in the top die. This allows the forging of close to net products with great precision. We are working with manufacturers to develop methods of manufacture using high integrity alloys, such as Inconel 718 and titanium 64. Our key piece of forging kit, a bespoke Schuler 3,500 kN Multiforge, also known as 'the upsetter,' is used for manufacturing preforms, which are then finally formed on our 2,100 tonne screw press.

Rotary friction welding

A fast and highly energy efficient process that benefits from enhanced integrity of weld assemblies, rotary friction welding uses friction instead of melting a material, which is useful for joining materials with a favourable microstructure, providing a narrow thin joint. It also allows us to join combinations of materials that we would be unable to join by any other means. At the AFRC, we have two rotary friction welding machines, the biggest of their kind in any UK research centre and use them in combination with other advanced manufacturing techniques.

Heating technologies

Our pioneering work in heating technology cuts across everything that we do. At the end of manufacturing processes, we can use heat treatments for various purposes, such as removing residual stresses. We can also choose the right heat treatment regime to make changes in a material's microstructure so that it is harder, less brittle or impact resistant. Enhancing our understanding and control of heating during manufacturing processes also reduces energy costs for the companies we work with, while increasing repeatability and efficiency during production.

Vibratory stress relief (VSR)

VSR is a low energy, low carbon footprint alternative to traditional heat treatment processes for managing residual stress. An alternative to heat treating parts using conventional methods, such as in furnaces, we clamp a vibration machine on to the part and the vibration releases the stress within. Providing portability, this also allows us to work on very large components that would be prone to restrictions with traditional heat treatment methods due to size. While VSR currently has a limited scope of application, we are spearheading its fundamental understanding and use across the manufacturing of high value, high integrity components.

Temperature Measurement

Temperature is a critical indicator of quality and consistency during manufacturing and so we offer a full suite of contact and non-contact temperature measurement. This includes bench-testing treatment, thermocouples, infrared cameras, thermal imaging, borescope and SPOT thermometer, alongside laser based measurement and phosphor thermometry. Devoted to enhancing process efficiency through temperature measurement, we are also proud to be part of EMPRESS 2, a collaborative project that boasts 27 academic and industry partners, including the National Physical Laboratory (NPL).

Automation of hot processes

Automating hot processes, such as forging brings significant benefits, such as improved productivity, part quality and repeatability. It can also enhance safety, by taking operators out of hot environments. These hot and dirty environments can however also prove challenging, with robots typically not dealing well with heavy parts. We offer significant expertise in this area and can provide advice on any forging automation project.

Key kit:

- Schuler 3,500 kN Multiforge
- Schuler 2,100T Screw Press
- 125 and 300 tonne rotary friction welding machine

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Material processing

Open die forging

Schuler 3500 kN multiforge

Technical info:
Built by Schuler AG according to AFRC specification. Allows individual programming of clamping and upsetting movements. Can optimise forging parameters. Shorter contact times achieved in the clamping and upsetting work sequence in comparison to conventional presses. Equipped with two bolsters heated up to 250˚C. One bolster can accommodate three small dies at 100 x 140 x 58 mm and another two, or one larger die.

- Dual-action, horizontal forging press driven by 2 servomotors
- High-performance servomotors enable programming of diverse ram speed profiles and stroke sequences
- Gripping capacity of vertical slide: 5,000 kN
- Upsetting capacity of horizontal derive: 3,500 kN
- Vertical and horizontal slide strokes: 140 x 200mm
- Accommodates a 3-station bolster
- Possibility of upsetting in the central station during the die closing with a force of 1,000 kN

500 Tonne hydraulic press

Technical info:
Small but versatile hydraulic press with a 500 tonne capacity for sheet forming and bulk forming a variety of materials. We use it for sheet forming, cold forming of gears, and open/closed die forming trials. Uses flat dies for compression.

- Max. sheet forming size: 350 mm x 250 mm
- Max. daylight: 400 mm
- Closing speed: 160 mm/sec – 250 mm/sec
- Max. ram speed: 6 mm/sec

Material processing

Closed die forging

Schuler 2,100 Tonne screw press

Technical info:
Widely used in industry and at the heart of what we do at the AFRC. One of the original pieces of our forging kit, we use it for manufacturing customer parts, high precision forging and fundamental research. Driven by direct electric drive, it benefits from excellent repeatability in subsequent strokes through enhanced speed and energy control. Integrated into an automated forging cell with robot loading/unloading and die spraying.

- Max. energy: 160 kJ
- Max. force: 21,000 kN
- Max. die temperature: 360˚C
- Max. stroke: 520 mm
- Die with flat surface available at: 290 x 180 x 120 mm

Material processing

Rotary friction welding

TWI 125 and 300 Tonne rotary friction welding machines

Technical info:
Rotary friction welding is a process that benefits from enhanced integrity of weld assemblies and is fast and highly energy efficient. We use it in combination with other advanced manufacturing techniques at the centre to help clients boost sustainability and save materials.

- Joint forging capacity ranging from 30,000 lbs to 300 tonnes
- Tri-mode capability
- Direct drive friction welding (DDFW)
- Inertia friction welding (IFW)
- Hybrid friction welding (combining DDFW & IFW)
- Solid cylinders or tubular welds can be achieved with outer diameters ranging from 35 mm to 250 mm

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Material processing

Heating technologies and temperature measurement

CMI gas fired furnace

Technical info:
A highly instrumented representative scale gas fired furnace, mainly used for investigating processes for preheating material and heat treatments. This bespoke piece of equipment allows us to study a wide range of factors (flue configuration, gas/air mix ratio, part stacking, door opening) that can affect heating performance, product quality and thermal efficiency. It also provides a mechanism for assessment of heating simulation capabilities, for example within DEFORM-HT.

- Maximum operating temperature of 1150˚C
- Maximum power: 180 kW (two burners of 90 kW each)
- Useful zone: 1 m^2 x 0.7 m High

Ambrell EKOHEAT 15 kW induction heating system

Technical info:
EKOHEAT induction heating systems for the 50 - 150 kHz range provide reliable and repeatable solutions for high speed heating of smaller parts where the part geometry or the coil size requires high frequency for efficient heating. Typical applications include heat-treating of steels/other alloys, shallow case depth hardening, and heating of steel, aluminium, copper or brass for brazing, shrink fitting, curing, forming and melting.

- Frequency: 50 – 150 kHz
- Power: 15 kW
- Capacity: billet 5-80 mm diameter, up to 50 mm long

Emissivity calibration furnace

Technical info:
Measures emissivity for numerous ceramic and metallic materials over a temperature range of 500-1150 degrees Celsius. Allows collection of highly accurate emissivity data under various conditions such as wavelength, furnace atmosphere, heating treatment, temperature and duration. This increases measurement accuracy and control with non-contact infrared (IR) thermometers and thermal cameras.

Land instruments thermal cameras

Technical info:
High resolution and high framerate thermal imaging camera. Used for furnace uniformity monitoring, internal check for cold spots and refractory damage, external check for hot spots, temperature monitoring of part during cooling, processing or transfer to press, forging die temperature monitoring, etc.

- ARC 8-14 µm 100˚C-1000˚C (requires specialist windows)
- ARC 8-14 µm 0-500˚C (requires specialist windows)
- NIR 1µm 800˚C-1400˚C (can be used through glass windows)
- NIR 1µm 700˚C-1200˚C (can be used through glass windows)

Land Instruments spot pyrometer

Technical info:
High performance pyrometers for fixed non-contact infrared spot temperature measurements. Several pyrometers (range of operating wavelengths, temperature ranges and process requirements) are available at AFRC. Used in industrial environments and are characterised by robust housings, excellent accuracy and high reliability.

- R110 400-1800 degC 1.0µm/1.1µm ratio fixed pyrometer – mostly emissivity independent
- R160 250-1600 degC 1.0µm/1.6µm ratio fixed pyrometer
- R210 125-1100 degC 2.1µm/2.4µm ratio fixed pyrometer
- 3.9µm mono wavelength handheld (requires specialist windows)

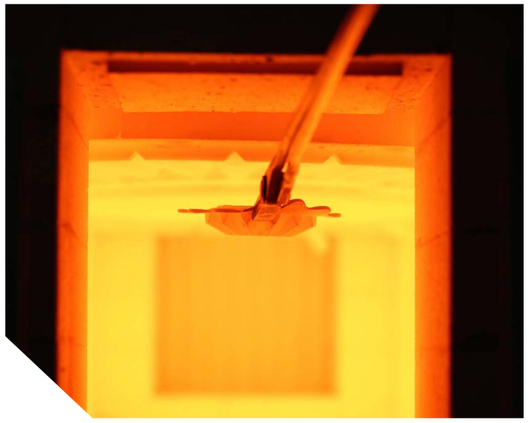
Testo 350 portable flue gas analysis system

Technical info:
Used to check gas composition uniformity inside the chamber volume (especially oxygen levels). Gas composition difference can affect part quality especially during long duration heat treatments. Assist provided for burner adjustments to reach the required O2 level, which is critical for improving energy efficiency.

Sensors fitted on our kit:
- O2, CO, CO2, CH4, Nox/ NO2
- Industrial gas sampling probe (use up to 1150˚C)

Furnaces and quench tanks

- CMI bespoke Gas Furnace
- Carbolite furnace HRF 7/324
- Carbolite furnace GPC 12/131
- Carbolite furnace LCF 14/350
- Electrotherm rotary furnace – 5700
- VFE/TAV TPH25/25/35 horizontal vacuum furnace
- Quench tank 1000L
- Polymer quench tank



FutureForge: transforming the forging supply chain

The data driven manufacturing space is experiencing an unprecedented rate of change. In response to this, we are introducing the world's most advanced hot forging platform, complete with one-of-a-kind, industry 4.0 ready demonstrator.

Together we can use this unique platform to improve our predictive power; we can explore less energy intensive methods of forging and we can accelerate the development of high integrity forged products.

Breathing new life into the forging supply chain, FutureForge will provide a deeper understanding of your products and processes. It will boost your efficiency and, ultimately, it will allow you to be more competitive.

An investment in Scotland's manufacturing future that will benefit the world

FutureForge is a £19 million investment for a new advanced manufacturing facility at the AFRC.

Launching in 2021, FutureForge is a truly unique and advanced hot-forging platform. It will help us support ambitious local businesses while attracting inward investment from global companies and OEM's.

Funders include the UK Aerospace Research and Technology Programme (delivered by the Department for Business, Energy and Industrial Strategy, Innovate UK and the Aerospace Technology Institute), Scottish Enterprise and the AFRC's High Value Manufacturing (HVM) Catapult funding.

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What is FutureForge?

Industry scale forging in a research environment

A bespoke, tri-modal forging press, enabling open die, closed die, and isothermal forging at industry representative scale will reinvigorate the forging supply chain by providing accelerated validation capability for high integrity forged products.

Developing a data driven future for forging

The accompanying FutureForge research programme will develop a data driven future for forging, transforming it from 'dark art' into a fully predictive process by validating simulation and modelling.

By determining process and microstructural behaviour, we can improve part quality, material and mechanical properties more quickly and efficiently, helping speed up new product introduction and cut your costs.

Making the next generation of products

To reach the Government's goal of net zero greenhouse gas emissions by 2050, the next generation of products for safety critical industries, such as aerospace, oil and gas and nuclear, will need to be more resource efficient but offer equivalent or enhanced mechanical properties. FutureForge will help us achieve this by exploring innovative and energy efficient forging techniques using a data driven approach.

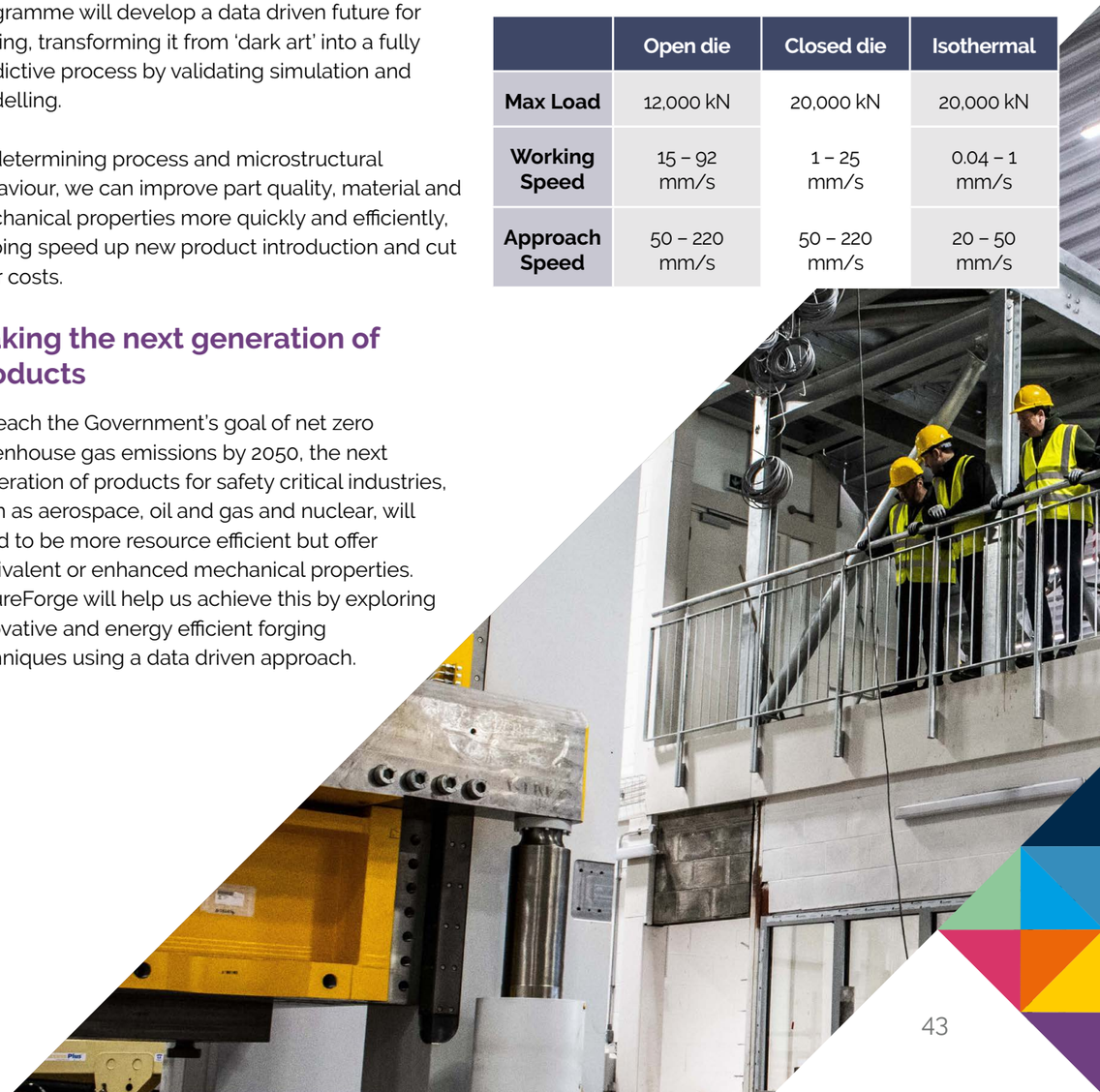
Technical data

The FutureForge facility will feature:

- Hot forging platform including a bespoke tri-modal industry demonstrator
- High accuracy manipulator
- 2x industrial furnaces
- Industry 4.0 data capture, connectivity and security
- High temperature die capability

Hot forging platform specification

	Open die	Closed die	Isothermal
Max Load	12,000 kN	20,000 kN	20,000 kN
Working Speed	15 – 92 mm/s	1 – 25 mm/s	0.04 – 1 mm/s
Approach Speed	50 – 220 mm/s	50 – 220 mm/s	20 – 50 mm/s



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Product development and innovation support

We will help you navigate the early design stages of product development ensuring that you do not lock in the wrong decisions about your product or manufacturing process.

Our product realisation team will work with you to visualise the whole product journey, exploring new methods of manufacture, linking you with key academic and industrial partners and slingshotting your requirements into a concept model using a robust design process.

We can also provide innovation support, embedding novel aspects deep within your product, including design, IP and manufacturing supply chain advice, helping bring your product to life, while delivering unique expertise that will enhance your competitive edge.

Key expertise:

Design

A great product idea is only as good as its design. Significant product costs are committed during the design phase, with design functionality and manufacturing closely linked from an early stage. In this digital world, we want instant results, which means quickly moving from conceptual design to a product ready for manufacture. Our engineers can quickly assess manufacturing implications and make efficient design decisions, enabling rapid product development, which opens the door to greater financial returns, more quickly, for the companies we work with.

Design for manufacture

Pushing boundaries in design, we explore the latest technology, such as model based definition, using up to the minute computer aided engineering software, techniques and methodology for design for manufacture that ensures product integrity. Delivering industrial needs today, we consider the whole design process, ensuring the correct input parameters, also taking into account materials and reliability of components, always with the aim of developing products that are fit for market.

Product development and market acceptance

Developing robust products going into safety critical applications means truly understanding those products and the strict regulations, codes and standards that they must meet. Our product realisation team appreciates the challenge of qualification and certification and works with manufacturers to achieve efficient product development, without compromising the validation journey, creating highly assured products that are accepted by the market and put into service more quickly. We confirm requirements, explore new methods of manufacture and develop designs, all while tapping into the enormous advanced manufacturing process expertise at the AFRC. Benefitting from a wide industrial and academic network, we can signpost additional expertise and funding and project partners that will give new products the best chance of success.

Innovation support

As a business, you may want to embrace innovation but need to ask whether you are truly set up to drive change, such as introducing a new process, product or material. From IP challenges to buying a new machine, innovation means different things to different firms. We see innovation as a change that allows something better to happen. It can be risky, but it can be just as risky to shy away from it. Our experienced business development team work across all the technical capabilities at the centre to make innovation manageable. We provide access to product advice, technical expertise and business support, including integrating innovation into design, Intellectual Property (IP) strategy, early seed investment options, exploring manufacturing processes and supply chain capability, finding funding, market research, business planning and more.

Process modelling

Wielding advanced numerical and analytical tools, our experienced team of modellers allow us to try out manufacturing processes in the virtual world, which saves costs and resources on physical trials.

Process modelling also allows us to visualise situations where we don't have line of sight, such as the activity in a furnace, while providing answers to critical questions, from 'is this possible?' to 'can we speed this up?'

Typically involving a complex and evolving sequence of events, modelling and simulation of manufacturing processes is challenging. Material behaviour is complex too; it is often hot and undergoing complicated deformations. Much of our success in this area is down to the skill of our modellers. They figure out what parameters are important, interpret results and drive decision-making based on the model.

In a unique position where we can construct our own algorithms and implement our own code, we can also tap into our materials characterisation expertise to define model parameters, before validating the data on our very own industrial equipment.

Key expertise:

Process parameter definition

Defining the optimal parameters for manufacturing processes, whether that is time, pressure, force or temperature boosts product quality, efficiency and productivity. It is especially critical for processes such as superplastic forming (SPF), hydroforming, radial forging, flow forming, rotary forging, ring rolling, etc. Using our advanced modelling expertise, we define these process parameters at the outset, achieving the best material performance and eliminating wasted resources, such as time, money and material, during customer trials.

Structural and mechanical integrity

Structural and mechanical integrity are crucial when designing products and components used across high pressure, high temperature environments. We work with industry clients of all sizes to perform accurate numerical and analytical studies, involving fracture and damage criteria. We can also employ fatigue or creep analyses when necessary.

Expertise in various FE commercial software

Our modellers are at the cutting edge of developments in FE software and their experience is vast, covering general and dedicated commercial software, such as Abaqus, Deform, NxT Forge, QForm, Simufact and PamStamp. As a research centre, we believe firmly in continued learning and our modellers are constantly enhancing their expertise and sharing ideas through seminars and relationships with key software developers.

In-house code development

Our in-house code development expertise complements our commercial software, allowing us to get the very best from it. We perform this widely across customer projects with our in-house code used in advanced FE analysis. Examples include complex material models implemented in Fortran user material subroutines and FE pre and post processing scripts coded in Matlab and Python.

Microstructural modelling

Material microstructure defines the final operational properties and quality of forged parts. We benefit from performing both industrial forging trials and mechanical and microstructural analysis under one roof. This microstructural modelling includes calibration of FE and microstructural models, benchmarking of available models and development of new models for advanced materials. Different types of microstructural modelling we perform include phenomenological modelling (JMAK-type models), coupled modelling and multi-scale modelling (full-field modelling DigiMu and crystal plasticity).

Residual stress modelling and simulation

In support of our world leading materials behaviour capability, we can specifically design tests that replicate manufacturing conditions, extending to modelling and prediction of residual stress during manufacturing. This allows us to improve the control of material characteristics and behaviours, offering important cost saving, part quality and efficiency boosting results for the companies we work with.

High performance computing for complex models

Some of the numerical modelling problems that we tackle are extremely complex. Flow forming, ring rolling and multi-scale microstructural models, for example, require high computational resources, such as the number of cores and amount of memory etc. Partnership with the ARCHIE-WeSt supercomputer allows us to make simulations any level of complexity and offer this service to the companies we work with. A regional supercomputer centre at the University of Strathclyde, it comprises of over 2500 INTEL Skylake 6138 cores for distributed parallel computing, two 3TB RAM large memory nodes and 210TB of high performance GPFS storage.

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