

Microscopy & Microtechniques

Strengthening aerospace quality assurance with advanced microscopy techniques

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How to assess and improve aerospace component quality and performance

Quality assurance is crucial in any industry, but nowhere more so than in aerospace manufacturing. Even the slightest defect in aircraft components could lead to catastrophic failures, making rigorous inspection and testing critical for safety and performance. Here, Dr Jan Kretschmer, Senior Sales Manager at Thermo Fisher Scientific, discusses how different microscopy techniques help quality assurance engineers to ensure the integrity of aerospace components.

Aircraft must operate in demanding conditions, including vibrations, high altitudes, fluctuating pressures and extreme temperatures. To ensure reliability, aerospace manufacturing is subject to strict regulations and industry standards, such as AS9100. A deep understanding of material properties — such as microstructure, strength and resistance to environmental stressors — is essential for developing aerospace components to comply with these standards.

This knowledge is not only important for compliance but also for optimising material performance. By studying how materials behave under stress, engineers can enhance durability, reduce weight and improve the overall efficiency of components.

Advanced imaging techniques such as scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) provide detailed insights into material composition and microstructure. These techniques help identify potential changes in material properties under extreme conditions and throughout various manufacturing processes, allowing for continuous improvement in aerospace materials and performance.

Preparing for extreme temperatures

High temperatures pose a significant challenge in aerospace applications, particularly in aircraft engines, where materials must maintain their strength and stability under extreme heat. Nickel-based superalloys are widely used in these applications due to their exceptional mechanical properties at high temperatures, including resistance to oxidation, creep and thermal fatigue.

To ensure these alloys can endure temperatures exceeding 2,000°C, high-resolution SEM is used. SEM provides detailed visualisation of the material's microstructure, allowing engineers to identify surface defects, grain boundaries and phase distributions. This is essential for understanding how the alloy behaves under high temperatures and stress.

EDS is also commonly used alongside SEM to map out the distribution of elements within a material. In the case of nickel-based superalloys, EDS can detect and analyse elements like nickel, chromium and aluminium, which are key to the alloy's performance. By analysing the composition and distribution of these elements, engineers can better understand how they affect an alloy's resistance to oxidation, creep and thermal fatigue at high temperatures. This knowledge then enables more precise material optimisation.

Particle analysis is also critical for studying the particles within superalloys, such as carbides and oxides. These particles play a significant role in the material's properties, including its resistance to creep and corrosion. Automated particle analysis systems can categorise and quantify particles based on their size, shape and distribution. By understanding these characteristics, engineers can refine material treatments, improving the alloy's overall durability and performance in extreme environments.

In addition to nickel-based alloys, thermal barrier coatings (TBCs) are often used to protect aerospace components from extreme heat. These coatings act as insulation, helping to safeguard components from thermal damage. Integrating SEM and EDS is invaluable for characterising TBCs, allowing engineers to observe how elements like magnesium and zirconium behave under repeated thermal cycling. This information is critical for optimising TBC formulations, ensuring they provide effective protection and extend the lifetime of components exposed to high temperatures.

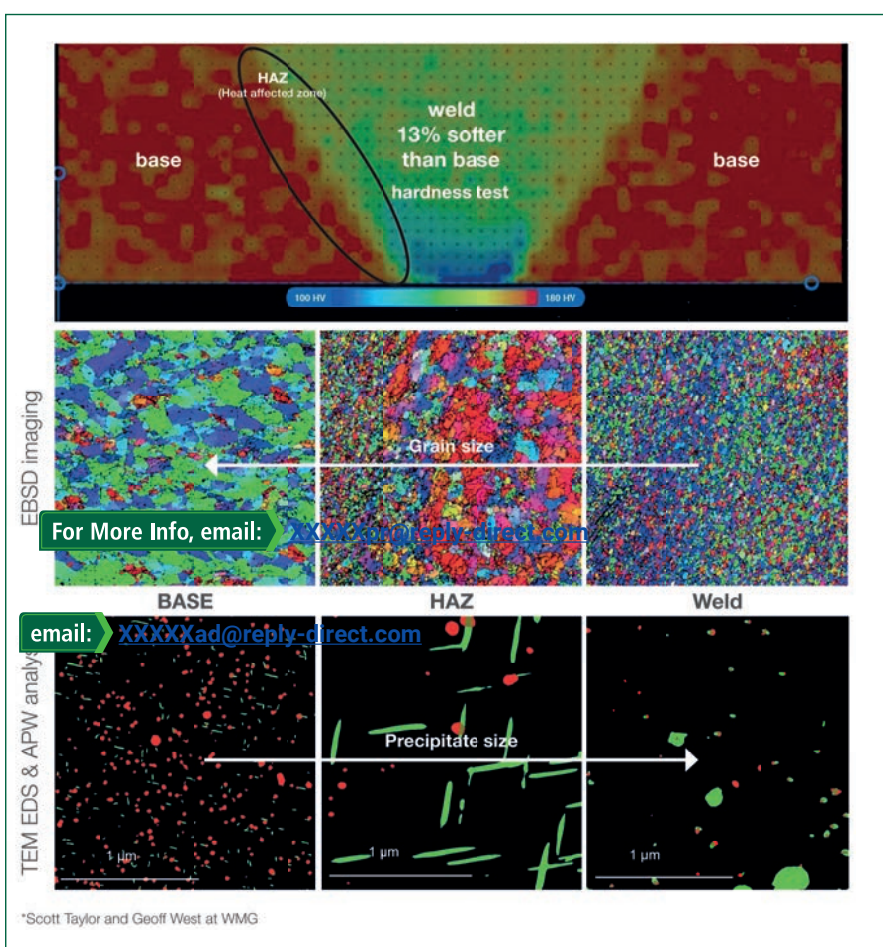
Identifying material changes during manufacturing

Verifying that materials can perform as required in difficult operating conditions is essential. However, it is important to recognise that manufacturing processes themselves can also significantly impact a material's microstructure and mechanical properties. To prevent defects and ensure reliability, it is crucial to closely monitor how these processes influence material behaviour.

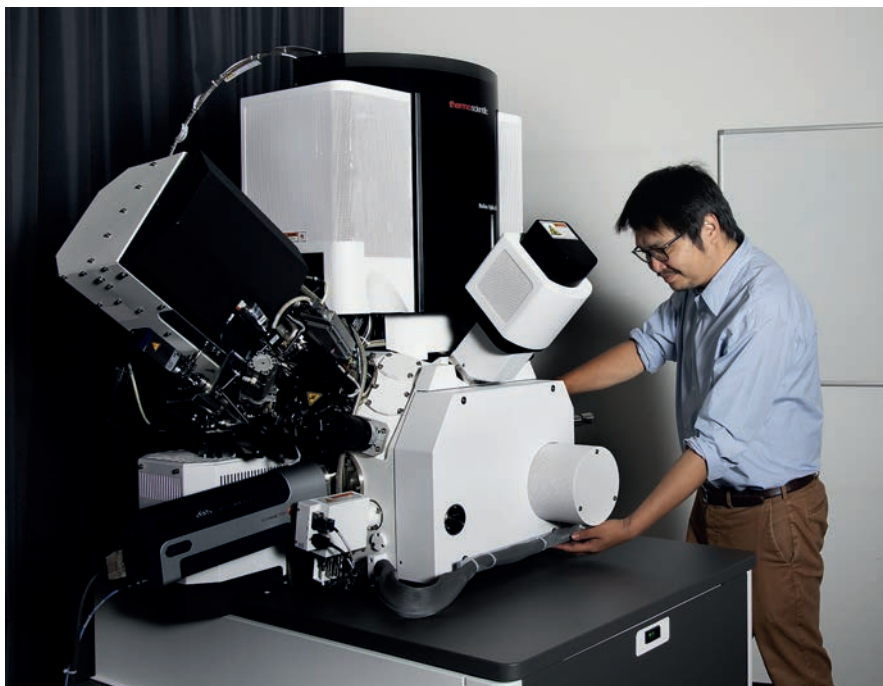
Aluminium alloys are widely used in aerospace due to their high strength-to-weight ratio and natural corrosion resistance, making them ideal for structural components such as wings, fuselages and engine casings. Aluminium-lithium (Al-Li) stiffened panels can be used to make these components more lightweight, but this often requires welding.

Friction stir welding (FSW) is typically used to join aluminium alloys such as Al-Li without having to melt them. Unlike traditional fusion welding, FSW operates at lower temperatures, reducing the risk of defects like hot cracking. However, this technique can alter the material's microstructure, especially in the weld zone. The result is often a softer region with reduced yield strength due to changes in grain structure, dislocation density and phase composition.

Understanding the changes induced by welding requires a combination of imaging techniques. To examine the key elements and the composition of intermetallic particles in the base material, heat-affected zone (HAZ) and weld, SEM is used. However, looking at particle changes alone is not sufficient to understand the reduction in strength observed in the weld. This is where electron backscatter diffraction (EBSD) mapping is helpful, revealing differences in grain size across the base, HAZ and weld.



Multiscale analysis of Al-Li Alloy: on the impact of friction stir welding process



Engineer using Thermo Fisher Scientific microscopy technology

While grain refinement in the weld could enhance strength, the potential reduction in dislocation density could have an adverse impact. The net effect on strength depends on the balance between these mechanisms, which can vary based on the alloy and welding conditions. Further analysis using a plasma focused ion beam (PFIB) and transmission electron microscope (TEM) provides insights into the distribution of edge and screw dislocations, clarifying how grain refinement and particle interactions contribute to overall material performance.

Combining these different techniques provides a more comprehensive understanding of the material's microstructure and mechanical properties compared to relying on any single method. By integrating these technologies, quality engineers can better identify the root causes of material behaviour changes. As a result, this allows them to optimise manufacturing processes and ultimately ensure the reliability and performance of aerospace components under varying conditions.

Recognising the impact of alloying

Alloying is beneficial for enhancing material properties such as strength or corrosion resistance. However, it's crucial for quality assurance engineers to examine the impact of incorporating alloying elements to materials.

For instance, adding elements such as copper, magnesium or manganese to the lightweight, corrosion-resistant aluminium alloy AA2024 can form different precipitates. The specific precipitates formed depend on the heat treatments applied, such as aging, hardening or annealing. For this reason, it is prudent to conduct a thorough analysis of raw materials at each stage of the manufacturing process.

An integrated system that combines multiple techniques such as SEM, EDS and EBSD offers significant advantages here. Together, these methods provide detailed insights into the alloy's composition and structure, crucial for quality control.

SEM and EDS offer high-resolution imaging to assess the composition, revealing the morphology and elemental distribution of intermetallic particles, while EBSD is used to map crystallographic phases, grain structure, orientation and morphology. Using these methods together provides a comprehensive picture of the precipitates and phases formed during aging treatments, which helps to improve heat treatments to attain specific material properties in aluminium alloys.

Advanced microscopy techniques are essential for assessing the integrity and reliability of aerospace components. By providing in-depth insights into the microstructure and composition of materials, tools like SEM, EDS and EBSD enable quality engineers to detect issues early and refine material properties. This ongoing cycle of inspection and optimisation drives continuous improvement, ensuring that aerospace components consistently meet rigorous industry standards for both safety and performance.