**Materials**

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Comments from the PB meeting

*G. Terzer:*

*Add heat exchangers for micro gas turbines*

The materials and coatings used for the hot gas path components in gas turbines, and their behaviour in service, place limitations on turbine performance and reliability, and represent significant elements in the capital and operating costs of the system.

In recent years, changing operational requirements, such as the use of alternative fuels and plant cycling, and factors affecting components lives and costs, have focused attention on specific materials issues. These include:

* The need for improved alloys and coatings (bond-coats, corrosion resistant coatings, TBCs, etc.) for increased efficiency and/or reliability, including ceramics and ceramic matrix composites for uncooled parts, e.g. in micro gas turbines;
* Hot corrosion of blades and vanes arising from the use of H2S-containing gas in offshore operations or biofuels in distributed power applications;
* The use of advanced and additive manufacturing methods for non-structural parts and component repair;
* Component materials inspection, condition assessment (linking to Condition Monitoring and Sensors and Instrumentation sections) and characterization of service-aged materials for life prediction modelling and residual life assessment;
* Condition assessment and durability of TBC coatings;
* The impact of flexible operation and plant cycling on component lifetimes, monitoring requirements and repair costs;
* Reduced usage of strategic and environmentally-damaging elements (re. compliance with EU REACH legislation);
* ‘Fit for purpose’ materials selection (i.e. cost effective materials selection to match the design and operating requirements, and no more).

While increased efficiency with low emissions have long been priority drivers for gas turbine OEMs, end-user focus for current markets has broadened to embrace reliability, operating costs and the ability to handle cheap fuels. In these circumstances, the challenge for the materials used has become more important and more diverse, as indicated above. Operators are now demanding higher reliability of components combined with the capability to maximize service lives, while minimizing the risk of unforeseen failures and extending maintenance intervals.

## Improved alloys, coatings and ceramics

The design of components for use in the hot gas paths of mod- ern gas turbines of all sizes and for all applications, involves:

* the production of complex-shaped parts to meet performance needs;
* systems of compatible materials which can be manufactured to produce the required shapes, with the required mechanical and chemical properties;
* the need to allow for inspection and repair.

As a result, understanding the behaviour of these materials systems, comprising base alloys, bond-coats/corrosion resistant coatings and TBCs during component manufacture and during service is now of fundamental importance if required performance levels and manageable operating costs are to be maintained.

It is also necessary to develop knowledge of the materials suitable for advanced cycles, such as closed bottoming cycles using supercritical CO2 or those using semi-closed oxy-firing where the turbine working fluid will be a mixture of CO2 and steam. Changes in design of the required turbomachinery combined with the changed operating environments will mean that translating existing materials knowledge will require qualification.

The application of monolithic ceramics and ceramic matrix composites is also an important development area, in particular for micro gas turbines where uncooled parts are required. Improved understanding of their failure mechanisms and in-service behaviour are required to ensure reliable operation.

**Hot corrosion behaviour**

Hot corrosion is a major cause of damage, and service failures, which is seen in many operational environments when aggressive fuel contaminants (e.g. alkali metals, sulphurous species, etc.) and poor air quality (e.g. containing alkali metal chlorides) fail to be satisfactorily reduced or eliminated through filtration or other means and reach the turbine’s hot gas path. The resulting formation of deposits and gaseous operating environments lead to very aggressive forms of ‘hot’ corrosion which can rapidly lead to failures. The successful elimination of such damage mechanisms must be tack- led through a combination of approaches to ensure that the aggressive combinations of contaminants do not reach the gas path with the use of materials and coatings with maximum resistance to this form of attack. The multiple factors involved in hot corrosion mechanisms mean that no single approach can be wholly successful on its own.

**The application of advanced and additive manufacturing**

Advanced and additive manufacturing techniques are being explored by OEMs, third party suppliers and operators for the manufacture of new parts to reduce costs or provide new materials compositions/ structures which cannot be achieved through conventional ‘subtractive’ methods. These methods can also be used as a repair option. However, these new or repaired parts, when used, must not compromise the mechanical performance, environmental resistance or the life of plant components.

Additive manufacturing (AM) processes allow production of components with geometries which are impossible to produce using conventional manufacturing through a layer-by-layer material addition process. This process opens up new design opportunities which could have significant advantages where intricate geometries may be beneficial, such as fuel injectors for gas turbine engines, heat exchangers, gas turbine blades or other aggressive environment applications found in energy technologies. In addition, when components have to be repaired, damaged regions of a component can be removed and replaced via an AM process. For the end user of the component which has been manufactured or repaired in this way, it is important that the materials behave in a predictable manner which is equivalent to those produced in a more conventional way.

**Inspection and characterisation of ex-service parts for component life extension**

There is an ongoing challenge to develop understanding of how on-line or off-line component monitoring or inspection techniques can be used to determine the condition of the materials used in the components, and hence inform an assessment of the component’s condition with respect to it continuing in service. Stretching routine maintenance intervals to reduce operating costs has been a continuing aim, although the growing use of gas turbines for flexible generation or with low quality fuels have required more regular inspections to help avoid problems. Relating ex-service component micro- structures to monitoring/inspection data, and its application in predicting the remnant life of the component remains an important area of research.

**Condition assessment and durability of TBCs**

TBC systems are based on yttria-stabilised zirconia or other formulations. Flexible plant operation to meet cyclic demands leads to additional thermal cycles which impacts directly on the risk of spallation of TBCs. Premature spalling of TBCs reduces component lives and increases costs through in- creased need for blade refurbishment. Improved on-line and off-line monitoring and inspection techniques are required to ensure costs are managed to avoid unforeseen failures and excessive maintenance/refurbishment costs.

**Impact of flexible operation**

The increased cycling of gas turbines in power generation applications has led to increasing incidences of unforeseen failures through fatigue and related mechanisms, as well as the premature spallation of protective coating systems. The current practice of applying the highest temperature performing base alloys with protective coatings may not provide an optimum approach where plants are designed for flexibility, rather than efficiency and low-NOx performance. Research into the costs of different approaches across the full materials life cycle may lead to alternative strategies which have potential to reduce operating costs.

**Reduced usage of strategic and environmentally-damaging elements**

European legislation requiring the registration, evaluation and authorisation of specific chemicals that can be considered injurious to health (REACH) came into force in 2007. This has implications in many aspects of gas turbine component manufacture and use, as both chromium (hexavalent chrome) and nickel (notably fine nickel oxide particles) are on this list of SVHC (substances of very high concern) – those that are considered carcinogenic or offer risks to health – along with some 26 other base materials or alloying additions found in our structural materials and coating systems. Many alloys and coatings in common gas turbine use will need to be registered and the implications for component manufacture, performance and repair need to be considered. For example, corrosion by-products that give rise to chromium-6 release is an area of concern.

