Reducing scrap rates for advanced turbine blading

Technology development is needed to reduce the current rather high scrap rates for blading in advanced gas turbines. A "semi-conservative" approach, combining existing aircraft technology with the experience that major repair and coating shops have in refurbishing stationary gas turbines, will ensure that financial benefits will outweigh additional technical risks.

Norbert Czech*, NC Consulting, Dorsten, Germany

The "new generation" of gas turbines that entered the market some years ago has combined cycle efficiencies of about 58 per cent, while gas turbine vendors worldwide are now working on getting the figure up to 60 per cent. The means of achieving this increase, however, will be mainly based on the upgrading and upscaling of key technologies that have been introduced in the 58 per cent family.

The move to increased efficiency has necessitated the use of new technologies. At the same time, the liberalisation of the electricity markets has put great pressure on the life cycle costs of the new gas turbine types. For the very first generation of high efficiency machines, the situation was different due to the overriding importance attached to achieving the promised efficiency and cost. The majority of the OEMs put this on this goal. But, as a consequence of the new market situation, it is no longer acceptable to have unplanned outages and high scrap rates for expensive hot gas path components due to poor design. Neither will the market tolerate non-existence of operational experience and the absence of the new technologies needed to repair the advanced machines.

In some cases the turbine blades exposed to the highest temperatures suffer from scrap rates of 25 to 50 per cent. Unfortunately, it is the most expensive parts like the SX (single crystal) and DS (directionally solidified) blades - with a value of over 5,000 euro each - that have the highest scrap rates and thus a dominant influence on life cycle costs.

Taking all these factors together, it is the goal of all parties in the game to reduce scrap rates through the introduction of innovative repair and refurbishment techniques.

Features of advanced blading

The following main features have been introduced into the hot sections of advanced gas turbines in the past 5 years:

- New cooling techniques comprising numerous perforations of the blade walls to achieve a film cooling effect. The holes have a more or less cylindrical cross section in most cases (resulting from laser-drilling) but in some applications trapezoidal "shaped holes" are also in use.
- To allow increased cooling efficiency, the blade walls have become ever thinner and

*The author was with Siemens for over 18 years in gas turbine design, and is now an independent consultant.
complicated internal cooling channel structures have been introduced. This approach, however, cannot work in areas where high thermal-mechanical stresses exist and the available amount of cooling air is not sufficient, e.g. the rotor blade tips and the vane platforms.

- As regards materials, single crystal and directionally solidified castings have been introduced, the latter even used in the rear turbine stages. This has been done mainly to increase thermal fatigue resistance but a part of this gain in properties had to be sacrificed to overcome the notch effect of the film-cooling holes and the metallurgical imperfections caused by the laser drilling process.
- Alloys with higher strength (gained by having a high volume fraction of the γ phase) but poorer resistance to hot corrosion (due to the reduction in chromium) are used that rely on a reliable coating for protection against the environment. The OEMs have decided to take this approach because gas turbine conditions are chemically less aggressive than they were a decade or two ago because of the rise of natural gas as the predominant turbine fuel.
- Coatings have been upgraded significantly. Complex MCAlYs have found their way also to the rear turbine stages, replacing diffusion type coatings. Thermal barrier coatings (TBCs) are meanwhile used as a design feature – and not just as a "bandage" (for life extension), as they used to be. There is some scientific discussion as to whether it is necessary to use expensive EB-PVD (electron beam physical vapour deposition) deposited TBCs rather than APS (atmospheric plasma spray) ceramics – the information available being strongly influenced by the particular test conditions. What we can say is that where the TBC may have come off for some reason or been overheated the bondcoat will be oxidised in the short term and the base material attacked.
- Internal coatings (mostly CVD (chemical vapour deposition)-aluminising) are being used to protect the thin walls of highly stressed blades and vanes from oxidative attack. Although the cooling air temperatures are quite low compared with the hot gas, less material degradation can be tolerated due to the prevailing tensile stresses and the danger of critical crack growth on the internal surfaces.

Figure 1 shows a typical advanced rotating blade with film cooling and TBC, while Figure 2 represents a typical stator vane.

Though many of the new technologies have been derived from existing aircraft engine practice, considerable R&D effort had, and still has, to go into adjusting the systems to the different requirements in stationary gas turbines, e.g. longer times at high temperatures, longer overhaul periods, more hostile environment etc.

Also the scaling aspects must not be forgotten: some LPPS (low pressure plasma spray)-coated parts have a weight of over 30 kg. Together with the masking and fixing tool a mass of more than 50 kg has to be heated up and kept at coating temperature. Coating facilities specialised in small aircraft components are not really suitable for this. Similar
tect and repair all cracks present, NDT methods like eddy current and dye penetrant testing must achieve lower detection limits. Blending of cracks and/or worn areas has to be done with minimum energy input. To ensure reproducible results, appropriate inspection instrumentation, e.g. for wall thickness measurements, has to be chosen and qualified. Welding and brazing methods must result in bonding with high strength. The techniques of welding relatively high alpha-alloys have made good progress. Brazing is the technology of choice to fill narrow cracks without blending. Repairable cracks must be completely cleaned of debris and any oxides that may have grown on the alloy. The best method for "fine cleaning" is a chemical one in which hydrogen fluoride is the active component.

- Thin walls that have suffered from excessive oxidation (caused by poor cooling and/or premature failure of the coating) must be blended out carefully down to certain minimum levels. The aerodynamic surface has to be recontoured in these areas by, e.g. overlay welding, brazing or parent metal thermal spray. It must be borne in mind that the original base material strength will not be reached, however 60-70 per cent seems to be achievable by welding and brazing. Recontouring of blended areas by overlay welding or (preferably) overlay brazing does not necessarily need to fulfill high strength requirements. However, it must result in good bonding to the substrate and the repaired area must be machineable to the final shape. The heat input during the repair has to be kept as low as possible and hot tearing (crack formation) or incipient melting must be avoided completely.
- Tip rubbing on rotor blades can occur, as in conventional machinery. In case of SX and DS castings the repair must be done in a way that avoids recrystallisation and/or secondary grain boundaries. Several patent applications are pending in this area.

- SX blades must be checked (using a repre
sentative sample) for recrystallisation in areas with deformations, eg caused by foreign object damage. The OEMs have defined conservative limits for the recrystallisation effect.

- The ceramic layer of the TBC coatings can usually be "stripped" (either mechanically by grit blasting or chemically in a salt bath) with no major problems. However, the bond coat, which in most cases consists of high aluminium MCrAlY, may be difficult to remove mechanically without causing unacceptable damage to the thin walls. This must be expected particularly in overheated areas where the bondcoat has been converted into oxide (alumina). Since simple acid stripping has no chance of dissolving alumina, more sophisticated methods like high pressure water jetting or the proprietary SICLEAN process have to be used.

- The main problem in the refurbishment of film-cooled blading is recoating. Re coating is the final operation after the refurbishment and hence has to be done last. In general the techniques used for this purpose are the same as for the coating of new parts, however, it must be taken into account that repaired parts may have different surface properties requiring special measures during the coating process. Another feature is that some parts have a different production sequence in the new and the refurbished condition, ie the recoating has to be done with existing cooling holes whereas on new parts the holes are usually drilled after deposition of the (metallic) coating. Thermal spray (T) methods (mainly LPPS in the case of MCrAlY coatings) used for the deposition of bondcoats and free-standing coatings are line-of-sight processes and therefore have a tendency to build up coating material also in areas where it is not desired, eg the cooling holes. Recoating of such parts requires special care to avoid plugging of the holes, the so-called "coat-down effect". A microsection of a successful repair, a "shaped hole" of a blade that has been recoated by LPPS, is shown in Figure 5. As the microsection shows, this problem may be overcome, by modification of the coating robot program or by choosing non-TS processes like TREFOMETM, a galvanic procedure, or the classic diffusion type coatings, where possible. These are not line-of-sight and thus do not introduce material into cooling holes.

Recoating of the ceramic layer is without problems in the case of EB-PVD because the vapour will only lay down where solid material exists. On APS sprayed TBCs the cooling holes can be protected from plugging by the use of plastic sticks that are applied to the holes during spraying. The condition of the internal coatings can be studied from outside. It is therefore necessary to check a representative part by destructive examination or to rely on experience. In principle it is possible to protect the internal coating from being removed during the stripping of the

9. Specification of procedures and repair steps for the "remaining" parts.
10. Mechanical machining, eg blending of cracks and removal of deteriorated material.
11. Ductilisation heat treatment as a preparation for weld repair (where applicable).
12. TIG- or laser-weld repair.
13. Hydrogen fluoride cleaning, where applicable, to remove oxide debris.
14. Narrow gap brazing of cracks (including hot tears from weld repair).
15. Wide gap brazing to fill up blended material.
16. Parent metal LPPS spraying to rebuild structure (where applicable).
17. Machining to recontour airflow surfaces.
18. Recoating of internal cooling passages (where applicable).
19. Recoating with overlays (MCRAlY and TBC, where applicable). The preconditioning of the surface to be recoated depends heavily on the TBC application method.
20. Reassembly (coating inserts, baffles etc).
21. Inspection (visual, dye penetrant).
22. Diffusion type coating, external.
23. Final heat treatment (where applicable).
24. Final inspection and documentation.
25. Release parts.

A semi-conservative approach

Today, as already noted, gas turbine components have scrap rates of 25-50 per cent per refurbishment. Together with the "infant mortality" of parts that have not been designed appropriately, the gas turbine operating companies have to face a giant cost burden in terms of life cycle cost. The OEMs are trying to improve the situation, but their capabilities are limited and the development of the next gas turbine generation is currently occupying most of the human capacity. Long-term O&M contracts can offset some of the financial risk onto the OEM, but at the end of the day it will be the operators who will have to carry the load.

The goal of the technical development described above - which emphasises more progressive repair methods and more sensitive NDT - should be to halve the existing scrap rates in the short term (2-3 years). This can be achieved by adapting existing aircraft technology and combining it with the experience that major repair and coating shops have in the refurbishment of stationary gas turbines. The complicated production sequences do not necessarily need to be carried out in one place. It could be advantageous to organise a production chain of highly specialised companies each doing skilled work. This applies especially when extremely expensive technologies like EB-PVD have to be used. The impact this might have on turnaround times could be overcome easily by well-organised order management.

The introduction of innovative repair and refurbishment techniques can of course entail a little additional technical risk. However, with a semi-conservative approach, as described here, the financial benefits will greatly outweigh the costs.