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RESEARCH and TECHNOLOGY ORGANIZATION
85th MEETING of the STUCTURES and MATERIALS PANEL
WORKSHOP 3 « THERMAL BARRIER COATINGS »
AALBORG (DENMARK) - 15-16 OCTOBER 1997

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REPORT on the FINAL DISCUSSION
Thursday, october 16th 1997
15h10 - 16h25

Chairman : Alain LASALMONIE (SNECMA)
Recorder : Stefan DRAWIN (ONERA)

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A. Lasalmonie (SNECMA) opened the round table by rapidly summarizing the themes presented throughout the workshop (see table of contents above).

1. « THIN » TBC (AIRFOIL APPLICATIONS)

1.1 Thermal conductivity

1.1.1 Effect of microstructure

A. Lasalmonie (SNECMA) - Effects of grain size and shape, (macro-)defects (pores and cracks) and layering were presented in papers N°1, 6, 8, 9, 14, 20. The needs are more quantitative measurements and studies on the stability of the microstructure (*vs.* time and temperature).

U. Schulz (DLR) - The quantitative values needed are values for thermal conductivity after aging, not on as-deposited TBCs.

W. Brindley (NASA) - Yes, but informations on initial (as-deposited) and final microstructure, as well as on intermediate states, are needed too, to get an idea of the important parameters that govern microstructure evolution during aging.

1.1.2 Effect of composition

A. Lasalmonie (SNECMA) - Is 8YSZ (8 wt%-yttria partially stabilized zirconia), the composition that is the most studied and the most used industrially, really the most appropriate composition, since higher yttria contents seem to exhibit lower thermal conductivities? The role of dopant and the use of other oxides has also to be studied (needs for basic research).

P. Morrell (ROLLS-ROYCE) - Yes, as shown by Y. Jaslier in paper N°1, and in other studies, thermal conductivity decreases with increasing yttria content, but if the yttria content is higher than *ca.* 20 wt%, ordering phenomena appear and thermal conductivity increases.

The 8YSZ composition has been developed and optimized by Chromalloy by durability tests on *plasma-sprayed* coatings. This composition has, from then on, be « conservatively » adopted by the aeroengine industry.

W. Brindley (NASA) - Temescal 20YSZ EBPVD coatings exhibited nasty erosion problems.

A. Lasalmonie (SNECMA) - It is time now to investigate other compositions.

V.R. Parameswaran (NRC) - Magnesia stabilized zirconia has been tested, but gave bad results. Using ceria (at high content : 25%), good results were obtained up to 1600°C, but ceria was (partially) reduced to Ce_2O_3 by chromium and aluminum from the substrate.

P. Costa (ONERA) - If ceria and other rare earth oxides are to be studied, the oxides of the elements at the end of the series should give the best thermodynamic stability.

1.1.3 Modelling

A. Lasalmonie (SNECMA) - Modelling is important for optimizing the structure and the properties of TBCs. The trends need to be quantified and experimental validation are required.

To study by numerical simulation the influence of the morphology on thermal conductivity to produce guidelines for coating manufacturers is an interesting idea (see paper N°13). Can existing image analysis techniques, such as those developed *e.g.* for grain boundary studies on metallic alloys, be applied to TBCs?

R. Mévrel (ONERA) - The approaches seem to be different.

1.1.4 Measurements

A. Lasalmonie (SNECMA) - The thermal conductivity measurement techniques on TBCs, especially at high temperatures, should become more reliable and could be assessed by a Round Robin on standard specimens.

P. Morrell (ROLLS-ROYCE) - Such a Round Robin was performed five years ago in the United Kingdom.

Y. Jaslier (SNECMA) - SNECMA already performed an intercomparison campaign (two laboratories in France, one in the United-Kingdom, one in the United States).

W. Brindley (NASA) - The contributions of the radiative and conductive components of the thermal conductivity should be assessed.

Zimmermann (?XXX) - Experiences have been performed on uncoated polished substrates and 100 μm zirconia-coated substrates and showed that radiation should not be neglected.

1.2 Processing of TBCs

1.2.1 Plasma spraying (PS)

A. Lasalmonie (SNECMA) - The presented communications (papers N°3 and 4) have shown good improvements in the process control, a better understanding of the influence of deposition parameters and modelling of the coating formation.

Can better structures and properties be achieved by including columnar inner structure to PS splats, as those shown by P. Fauchais (paper N°3)?

Y. Jaslier (SNECMA) - The columns shown by P. Fauchais are generated by a solidification front starting from the cold substrate and proceeding towards the liquid part of the splat, whereas for the columnar structure in EBPVD coatings you have solidification (condensation) from the gas phase to the solid substrate : the properties may not be the same.

XXX (?) - A recent study by Boeing showed that LPPS TBCs exhibit a fivefold longer lifetime than APS coatings.

W. Brindley (NASA) - It has to be noticed that a great variability exists in the properties of PS TBCs from one coating manufacturer to the other. So, great care should be taken when comparisons are made!

There is place for both processes (PS and EBPVD) in aeroengines and other parameters than durability have to be taken into account.

XXX (??) - Have other studies on reproducibility of PS coatings been performed (*cf* paper N°4)?

A. Lasalmonie (SNECMA) - Equipments are now availavable and installed, for a good control of the reproducibility.

C. Moreau (NRCC) - A good control for a better reproducibility can be achieved by controlling the particle velocity and temperature and the substrate temperature. The latter depends of the type of thermal contact between splats.

XXX (??) - How much variability can be tolerated?

C. Moreau (NRCC) - For variations of 100°C for the substrate temperature, different coating microstructures were observed.

P. Morrell (ROLLS-ROYCE) - From the point of view of the manufacturer, the shape of the component to be coated is of prior importance. The now available processes are a compromise of what the engineers want and what they can get.

1.2.2 EBPVD

A. Lasalmonie (SNECMA) - Different coating structures and properties can be obtained by EBPVD. If we refer to the presentation by G. Marijnissen (INTERTURBINE, paper N°10), this is a process that has to be further controlled : the influence of a lot of parameters has to be studied.

V.R. Parameswaran (NRC) - Grading should have a good influence on the properties of the EBPVD coatings.

1.2.3 Layered structures

A. Lasalmonie (SNECMA) - Interesting results have been presented (*cf.* paper N°6), but no thermal stability and lifetime values are available for these TBCs. Furthermore, are these structures industrially feasable?

J.R. Nicholls (CRANFIELD Univ.) - These are still too new systems : they have only been tested at 1100°C for 50 hours.

A. Lasalmonie (SNECMA) - The layer thickness appears to be a fundamental parameter.

J.R. Nicholls (CRANFIELD Univ.) - Yes, the layers should have a thickness comprised between $\lambda/4$ and λ (λ : wavelength of the incident radiation) to efficiently reduce the radiative contribution to the thermal conductivity. Note that the layers deposited by K.S. Ravichandran (UTAH Univ., paper N°14) were either too thick (15 - 49 µm) or too thin (0.06 - 0.15 µm) to induce a noticeable reduction of the thermal conductivity.

1.2.4 Plasma assisted CVD

A. Lasalmonie (SNECMA) - This new deposition technique seems to present good potentials ; its application to coat real parts has not still to be demonstrated and the costs have to be evaluated.

V.R. Parameswaran (NRC) - The use of chlorides ($ZrCl_4$) may lead to environmental issues.

XXX (DLR) - The ability to coat compex-shaped parts remains questionable.

S. Drawin (ONERA) - The problems with chlorides can be solved even for industrial plants ; other zirconium precursors are currently studied. A larger deposition reactor will be built next year, that will be able to coat larger parts, as well coupons as blade and vanes.

J.R. Nicholls (CRANFIELD Univ.) - The use of a plasma will make it possible to deposit layered systems, similarly to what has been achieved in our laboratory.

1.3 Lifetime of TBCs

1.3.1 Role of bond coat, TGO and oxidation

A. Lasalmonie (SNECMA) - Differences in the coating properties are observed when different bond coats are used : how can they be explained? The role of the bond coat surface preparation (roughness) has to be assessed. Various failure modes are encountered in or at the TGO (Thermal Grown Oxide) : the failure mechanisms have to be understood more precisely.

M.R. Winstone (DERA) - Are the failure mechanisms the same for TBCs having experienced 1000 one-minute cycles and 1000 one-hour cycles? TBC manufacturers have large databases on the possible failure modes ...

W. Brindley (NASA) - Yes, TBCs cycled at maximum temperature for six or sixty minutes present different failure modes. It is thus important to design the right durability tests : maximum temperature, coolant temperature, time at maximum temperature, ...

For highly oxidized TBCs, failure occurs at locations where the experienced temperatures were the highest.

About the surface preparation, the presented paper (N°17) adressed PS coatings with a simplified (sine-wave) roughness. Can the conclusions be generalized to all PS coatings?

1.3.2 Testing methodology

A. Lasalmonie (SNECMA) - As shown by paper N°15, burner rig tests may be very difficult to interpret : there is a need to establish a testing methodology for the durability tests.

1.3.3 Modelling

A. Lasalmonie (SNECMA) - Thermomechanical modelling of the TBC system should allow a better understanding of the failure mechanisms.

1.3.4 Graded structures

A. Lasalmonie (SNECMA) - The feasability of such structures has been demonstrated, but extensive lifetime tests have still to be performed.

A. Lasalmonie (SNECMA) - Generally, what is missing is the users experience on failure mechanisms, on reliability and aging of the TBCs.

Another issue is the influence of the substrate (directionnally solidified alloys *vs.* single crystals, sulfur and titanium content and diffusion, ...).

P. Morrell (ROLLS-ROYCE) - Physical phenomena are now understood and coatings have been specifically designed by ROLLS-ROYCE.

J.R. Nicholls (CRANFIELD Univ.) - Different bond coats are needed for different single crystals : in general, now bond coats are designed for specific substrates.

Y. Jaslier (SNECMA) - In the single crystal substrates, the grain boundaries having been removed, sulfur cannot segregate at these locations and has to go somewhere else.

XXX (KLM) - Experience exists, but is not spread worldwide (proprietary data!).

1.4 Other properties

1.4.1 Erosion

A. Lasalmonie (SNECMA) - Can the erosion behaviour of PS coatings be improved?

C. Moreau (NRCC) - Yes, by using for instance powders with smaller particle size ... but several problems will then occur (feeding of the powder into the plasma torch, moisture sensitivity, cost, ...).

W. Brindley (NASA) - Another way to solve this problem would be to find an erosion-resistant material to spray on the leading edge (and having a lower thermal conductivity than the superalloy substrate).

C. Moreau (NRCC) - Here too, feedback from the users is needed.

P. Morrell (ROLLS-ROYCE) - Currently, TBCs behave well on combustor cans and vane platforms.

W. Brindley (NASA) - The problem is also to get the right informations from the TBC coated parts : this needs periodic inspections, inspections means, and inspection procedures.

P. Morrell (ROLLS-ROYCE) - And how will the metallic substrates be inspected if there is a TBC on it.

1.4.2 TBC repair

A. Lasalmonie (SNECMA) - How is the repair of TBCs mastered?

2. « THICK » TBC (COMBUSTOR APPLICATIONS)

2.1 TBC on free-standing components

XXX (??) - This is user-oriented for specific parts.

2.2 TBC for combustors

A. Lasalmonie (SNECMA) - Thick TBCs have to be compared to other solutions (CMC, cooled metals, ...).