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Alternative Materials for Performant TBCs: Short Review

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Abstract

Thermal Barrier Coating (TBC) is a thermal insulation, which enables the coated substrate material to work above its melting temperature. The TBCs have been used to enhance the performance of the gas turbine for aeronautic and energy applications. Yttria stabilized zirconia YSZ (ZrO_2+7-8 wt.% Y_2O_3) is a topcoat ceramic which is applied for more than 40 years to gas turbine components. YSZ has a high toughness and a good temperature capability up to about 1200 °C, higher operating temperatures is required for enhanced efficiency of gas turbine. Alternative materials for TBC application were developed during the last years allowing a higher temperature capability and lower thermal conductivity combined to higher toughness and thermochemical stability a of the TBCs.

Introduction

Ceramic coatings were first used in the late 1940s [1-3].These coatings have been applied to the nozzles of X-15 rockets and to the components of the combustion chamber of gas turbines in the 1960s [1]. The main role of these coatings is to reduce the surface temperature of the coated components. These coatings, designed Thermal Barrier Coatings (TBCs), have been used successfully since 1970s to extend the gas turbine components lifetime [4,5]. Since the publication of the first papers on TBCs applied to gas turbine blades in 1976 [6], the development of these coatings for hot sections of engines has become the focus of the scientists in the field of materials science [6,7].

Mini Review

The first ceramic materials applied to successful thermal barrier coatings are alumina (Al_2O_3) and zirconia-calcia (ZrO_2+CaO), these ceramics were deposited on Nichrome bond coat [8]. Nevertheless, these materials have shown their limits for more advanced applications of TBCs. In the case of alumina, his thermal conductivity is a relatively high [9] and forms also nonequilibrium phases called gama, eta, and delta phases, which transform at high temperature to the stable phase alpha [10]. This transformation induces shrinkage and associated cracking which would have a detrimental effect on coating life. In the case of zirconia-calcia and zirconia-magnesia. The problem is related to destabilization from the cubic (F-ZrO_2) phase to the monoclinic (M-ZrO_2) phase. Pure zirconia has three crystallographic forms: monoclinic from low temperatures up to around 1170 °C, quadratic between 1170 °C and 2300 °C and finally cubic up to the melting point around 2710 °C. After cooling to around 950 °C, the transformation of the quadratic phase into the monoclinic phase is accompanied by a volume expansion. This elongation initiates residual stresses and the appearance of cracks within the ceramic during thermal cycling, which therefore makes it impossible to use pure zirconia alone for thermal barrier application. That is why; many dopants (oxides), such as CaO, MgO, CeO_2, or Y_2O_3 were added to zirconia in order to totally or partially stabilize cubic or quadratic structures at low temperatures [8]. Yttrium is best suited to thermal barrier application since Yttria Zirconia (YSZ) has low thermal conductivity and mechanical properties superior to those of zirconia stabilized with the other dopants [11-13]. To give the thermal barrier good mechanical properties and thermal stability the Yttria level should be between 6 and 8% [14]. The thermal conductivity of bulk yttria partially stabilised zirconia YSZ and YSZ coatings were reported to be 0.7-1.4 W/mK (7.25wt.% YSZ) [15,16]. The YSZ has a high CTE (11×10^{-6} K^{-1}) [11], which is close to that of the coated superalloy substrate (14×10^{-6} K^{-1}) [12], it helps to reduce induced stresses from the thermal expansion mismatch. Neverthless, a mismatch still remains inducing crack propagation within the coatings despite its high toughness. Therefore, more demanding performances are required to this technology, and there will be a continuing need to develop more durable TBCs. A numerous works on various aspects are found in the literature [12,13,16-23].

The intensive research for new TBC materials results in several groups of different ceramic [16]: (1) zirconia doped with different Rare-Earth (RE) cations (defect cluster TBC's), (2) perovskites, (3) hexa-aluminates, and (4) pyrochlores have been suggested as promising new top coat materials (see Table 1 for the chemical compositions and main advantage of these materials).

Table 1: Composition and main advantages of alternative material groups for TBCs applications [16].

Material Group	Composition	Main advantages
Defect Cluster TBCs	Zirconia is doped with oxides of different rare-earth (RE) cations: ZrO_2-Y_2O_3-Gd_2O_3-Yb_2O_3	Lower thermal conductivity compared about 1.7 W/mK [24]
Perovskites	Zirconates $AZrO_3$ (A=Sr, Ba, Ca)/$SrZrO_3$ Complex forms ABO_3 (A=Ba, La, B=(paired Mg,Ta, Al, La)/$Ba(Mg_{1/3}Ta_{2/3})O_3$	High melting point: $SrZrO_3$; 2650 °C, $Ba(Mg_{1/3}Ta_{2/3})O_3$; 3100 °C [25].
Hexaaluminates	(La, Nd)$MAl_{11}O_{19}$ (M = Mg, Mn to Zn, Cr or Sm)/ $LaMgAl_{11}O_{19}$/ $LaTi_2Al_9O_{19}$ $AB_xAl_{12-x}O_{19}$	Low young's modulus, high sintering resistance, structural and thermochemical stability up to 1400 °C [26,27].
Pyrochlores	$A_2B_2O_7$ A and B are 3 + or 2 + and 4 + or 5 + cations/$La_2Zr_2O_7$	Good combination low thermal conductivity and high temperature phase stability and pronounced CMAS resistance [28]

Summary

The present paper presents a short review on the early TBCs applications and their development during the last decades. The properties of Yttria Stabilized Zirconia (YSZ) as well as their advantages were shortly reported. It has been shown in the TBC literature of the last years the potential of Hexa-aluminates and pyrochlores in increasing the TBC performance, these groups of ceramic applied to TBC exhibit a high sintering resistance, thermochemical stability up to 1400 °C and a significant CMAS resistance.

References

1. Miller RA (1987) Current status of thermal barrier coating: an overview. Surf Coat Technol 30(1): 1-11.
2. Harrison WN, Moore DG, Richmond JC (1947) Review of an investigation of ceramic coatings for metallic turbine parts and other high-temperature applications. NACA TN-1186.
3. Bartoo ER, Clure JL (1953) Experimental investigation of air-cooled turbine blades in turbojet engine XIII -endurance evaluation of several protective coatings applied to turbine blades of nonstrategic steels. NACA RM-E53E18.
4. Stecura S (1976) Two-layer thermal barrier coating for turbine airfoils-furnace and burner rig test results. NASA Tech (National Aeronautics and Space Administration), Memo. X-3425.
5. Liebert CH, Jacobs RE, Stecura S, Morse CR (1976) Durability of zirconia thermalbarrier ceramic coatings on air-cooled turbine blades in cyclic jet engine operation. NASA Tech (National Aeronautics and Space Administration), Memo. X-3410.
6. Lakiza SM, Grechanyuk MI, Ruban OK, Redko VP, Glabay MS, et al. (2018) Thermal barrier coatings: current status, search, and analysis. Powder Metallurgy and Metal Ceramics 57: 82-113.
7. Feuerstein A, Knapp J, Taylor T, Ashary V, Bolcavage A, et al. (2008) Technical and economical aspects of current thermal barrier coating systems for gas turbine engines by thermal spray and EB-PVD: A review. J Therm Spray Technol 17: 199-213.
8. Miller RA (1997) Thermal barrier coatings for aircraft engines: History and directions. J Therm Spray Technol 6(1): 35-42.
9. Wilkes KE, Lagedrost JE (1973) Thermophysical properties of plasma sprayed coatings. NASA (National Aeronautics and Space Administration), CR-121144.
10. Mebdoua Y, Vardelle A, Fauchais P, Gobin D (2010) Modelling the nucleation process in alumina lamellae deposited on a steel substrate. International Journal of Thermal Sciences 49(3): 522-528.
11. Hasselman DPH, Johnson LF, Bentsen LD, Rahmatullah S, Hong LL, et al. (1987) Thermal diffusivity and conductivity of dense polycrystalline ZrO_2 ceramics: A survey. Am Ceram Soc Bull 66(5): 799-806.
12. Cao XQ, Vassen R, Stoever D (2004) Ceramic materials for thermal barrier coatings. J Eur Ceram Soc 24(1): 1-10.
13. Kumar V, Kandasubramanian B (2016) Processing and design methodologies for advanced and novel thermal barrier coatings for engineering application. Particuology 27: 1-29.
14. Stecura S (1979) Effects of compositional changes on the performance of a thermal barrier coating system. NASA TM-78976, National Aeronautics and Space Administration.
15. Pawlowski L, Lombard D, Fauchais P (1985) Structure-thermal properties-relationship in plasma sprayed zirconia coatings. J Vac Sci Technol A 3(6): 2494-2500.
16. Bakan E, Vaßen R (2017) Ceramic top coats of plasma-sprayed thermal barrier coatings: Materials, processes, and properties. J Therm Spray Tech 26: 992-1010.
17. Viswanathan V, Gopal D, Sampath S (2015) Multilayer, multimaterial thermal barrier coating systems: Design, synthesis, and performance assessment. J Am Ceram Soc 98(6): 1769-1777.
18. Vaßen R, Bakan E, Mack D, Schwartz SL, Sebold D, et al. (2020) Performance of YSZ and $Gd_2Zr_2O_7$/YSZ double layer thermal barrier coatings in burner rig tests. Journal of the European Ceramic Society 40(2): 480-490.
19. Kumar N, Gupta M, Mack DE, Mauer G, Vaßen R (2021) Columnar thermal barrier coatings produced by different thermal spray processes. J Therm Spray Tech 30: 1437-1452.
20. Bakan E, Sohn YJ, Vaßen R (2021) Microstructure and phase composition evolution of silicon-hafnia feedstock during plasma spraying and following cyclic oxidation. Acta Materialia 214: 117007.
21. Wolf M, Mack DE, Mauer G, Guillon O, Vaßen R (2021) Crystalline ytterbium disilicate environmental barrier coatings made by high velocity oxygen fuel spraying. Int J Appl Ceram Technol 19(1): 210-220.
22. Yi H, Pengan Z, Muzhang H, Zesheng Y, Yingjie F, et al. (2022) In-situ synthesis of gadolinium niobate quasi-binary composites with balanced mechanical and thermal properties for thermal barrier coatings. Journal of Advanced Ceramics 11(9): 1445-1456.
23. Vaßen R, Bakan E, Mack DE, Guillon O (2022) A perspective on thermally sprayed thermal barrier coatings: current status and trends. J Therm Spray Tech 31: 685-698.
24. Zhu D, Miller RA (2005) Development of advanced low conductivity thermal barrier coatings. Int J Appl Ceram Technol 1(1): 86-94.
25. Ma W, Mack D, Malzbender J, Vaßen R, Stover D (2008) Yb_2O_3 and Gd_2O_3 doped strontium zirconate for thermal barrier coatings. J Eur Ceram Soc 28(16): 3071-3081.
26. Cinibulk MK (1995) Thermal stability of some hexaluminates at 1400 °C. J Mater Sci Lett 14(9): 651-654.
27. Gadow R, Lischka M (2002) Lanthanum hexaaluminate-novel thermal barrier coatings for gas turbine applications-materials and process development. Surf Coat Technol 151-152: 392-399.
28. Subramanian MA, Aravamudan G, Subba Rao GV (1983) Oxide pyrohlores-A review. Prog Solid State Chem 15(2): 55-143.