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Thermal Barrier Coatings for Aerospace Applications

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Abstract

Thermal barrier coatings (TBCs) play a significant role in the applications that are unmasked at high temperatures. These TBCs are used in diesel and combustion engines and especially in aerospace gas engines due to their extreme thermal resistant nature. Here the discussion focuses on methods like physical vapour deposition, different plasma-sprayed techniques, GPX that are incorporated to get TBCs and how these techniques influence various problems and properties of TBCs their thickness and composition of materials used, are considered that makes way to improve the durability of TBCs.

Keywords: *Thermal Barrier Coatings (TBC), Plasma Spray, Physical Vapour Deposition (PVD), Electron Beam Physical Vapour Deposition (EB-PVD)*

INTRODUCTION

Thermal barrier coatings (TBCs) are first used in aerospace later in diesel and combustion engines. They were subjected to greater compressive loads and thermal shocks than in aerospace to check their efficiency at high temperatures in diesel and combustion engines. Among many coating techniques GPX TBCs were more beneficial which provided high precision, oxidation resistant and non-melting coatings [1]. But physical vapour deposition (PVD) and plasma sprayed methods are also well known for TBCs such that PVD are widely used at very high temperatures [2]. TBCs in aerospace applications can be significantly different than those for power generation and transportation and also helpful in reducing thermal transients related to turbo pumps of space shuttle [3]. To have extended durability Yttria stabilized zirconia top coat and metallic bond coat deposited on to super alloy (Ni based) is used. TBCs by electron beam physical vapour deposition (EB-PVD) are used in high performance application of about 1200˚C. The melting temperature of Ni based super alloy is important to incorporate them in present and future development [4,8]. The percentage of chemical composition in TBCs is also important in bond coat and ceramic top coat done by plasma spraying also the oxidation breakaway occurs due oxide layer growth between these coats will increase the width of the coatings [6,7]. Along with these techniques laser drilling is also one which is used to drill holes in super alloys to create cooling holes to balance the temperature but was not desirable since it lead to some failure [5]. To have flexibility and to use between switched panels to experience multi-functions such as low heat transfers and improved thermo-mechanical responses [9]. These TBCs can also be employed using advanced structural ceramics can be exposed to very temperature level about (>1150˚C) [10].

LITERATURE REVIEW

Daniel W Parker carried a work on “Thermal barrier coatings for gas turbines, automotive engines and diesel equipment”, where results showed that GPX method with high precision TBCs of 0.25mm thick is enough to reduce the surface temperature of component (1050˚F) with increased thermal efficiency, reduced thermal induced strain and oxidation resistance properties. Also found that coatings would fail when their thickness crosses 3 inch [1].

R. A. Miller worked on “Thermal Barrier Coatings for Aircraft Engines: History and Directions”, showed that TBCs with plasma sprayed and PVD are important but TBCs with PVD is more suitable for high temperature application. Also showed that incorporation of alumina with ZrO_2 is not desirable because alumina was non-equilibrium, poses thermal conductivity and undergoes phase transitions can lead to monoclinic phase that is undesirable below 1140˚C. And it resulted that amount of addition of yttria to stabilize zirconia to be decreased from 12%-20% to 6%-8% to increase efficiency also it is superior than zirconia with calcium and zirconia with magnesium [2].

J. A. Nesbitt carried work on “Thermal modelling of various thermal barrier coatings in a high heat flux rocket engine”, in which 1D and 2D thermal models of rods(coated and uncoated) and tubes were used instead of TBCs using median plasma sprayed ZrO_2-Y_2O_3 cermet coatings which showed that coatings 0.1mm thick ZrO_2-Y_2O_3 and 0.2mm thick ZrO_2-Y_2O_3 can be used at 300˚C and 500˚C respectively on tube. Also showed the variation of thermal conductivity from 0.8 to 2 W/mK for 100˚C in cooled turbines in aero gas engine [3].

Uwe Schulz, Christoph Leyens, Klaus Fritscher, Manfred Peters, Bilge Saruhan-Brings, Odile Lavigne, Jean-Marc Dorvaux, Martine Poulain, Remy Mévrel, Michaël Caliez carried work on “Some recent trends in research and technology of advanced thermal barrier coatings”, and their result showed that there were two competing technologies for TBCs those were plasma spraying(PS) on hot components and EB-PVD on smooth surface. EB-PVD with superiority in lifetime was observed and widely used in industrial gas turbines for power generation over PS. Also observed that advanced TBCs system have to be developed in order to accommodate the further anticipated increase in engine performance [4].

H. K. Sezer, A. J. Pinkerton, Lin Li, and P. Byrd carried work on “An investigation into delamination mechanisms in inclined laser drilling of thermal barrier coated aerospace superalloys”, and reported that if the laser irradiation temperature and power density is greater than melting temperature of material then it would surely melt that and it is further removed by rapid vaporization. And showed that as the hole depth increases the portion visible for laser drilling decreases which results in reduced laser power density. And vapour pressure model was used to compute the mathematical interpretation of momentum and continuity equations for each phases and were solved [5].

Gabriel Maria Ingo, Tilde de Caro worked on “Chemical aspects of plasma spraying of zirconia-based thermal barrier coatings”, they obtained 8% Y_2O_3–ZrO_2 and 25.5% CeO_2 and 2.5 Y_2O_3–ZrO_2 TBCs using APS and LPPS and their chemical composition is studied through XPS and SEM. And found that occurrence of chemical physical phenomenon leads to change in TBC colour and further the plasma spraying effects the chemical state on coating materials [6].

E.P. Busso, H.E. Evans b, Z.Q. Qian c , M.P. Taylor has carried work on “Effects of breakaway oxidation on local stresses in thermal barrier coatings”, and showed that the oxidation protection in TBCs was due to growth of alumina would further deplete the bond coat in turn results in premature chemical failure[7].

Xiaolong Chen, Yanfei Zhang, Xinhua Zhong, Zhenhua Xu, Jiangfeng Zhang, Yongliang Cheng, Yu Zhao, Yangjia Liu, Xizhi Fan, Ying Wang, Hongmei Ma, Xueqiang Cao worked on “Thermal cycling behaviors of the plasma sprayed thermal barrier coatings of hexaluminates with magnetoplumbite structure” and reported that they used four different hexaluminates of different proportion were used for coatings by plasma sprayed to the substrate of thickness 3mm. The thermal cycling test was conducted by heating the coatings to 1250˚C±30˚C from room temperature for 5min and quenching for 2min. After periodic repetition found that exactly 5% coating was lost and was analysed by SEM [8].

Cody H. Nguyena, K. Chandrashekhara b, Victor Birman worked on “Multifunctional thermal barrier coating in aerospace sandwich panels” and showed that these multifunctional titanium alloy based TBCs with thickness 0.102cm, explores mainly two issues heat transfer and improved structures. Panels are analysed by subjecting it to thermal loading and finite element method and shown that there exists a proper thermal gradient between inner and outer layer of TBCs. Because of proper heat gradient no stress acts on TBCs resulted in high stiffness and strength [9].

Nitin P. Padture worked on “Advanced structural ceramics in aerospace propulsion”, and showed that super alloys are incorporated with TBCs to operate in high temperature but use of composite material that is ZrO_2 partially stabilized by 7wt% Y_2O_3 instead of super alloys would further increase the performance. [10]

METHODOLOGY

GPX method was used to develop TBCs and found that 0.25mm thick TBC is enough to reduce surface temperature at 1050˚F by 200-300˚F. TBCs through GPX have proper adhesion between bond coat and ceramic coat which hinders oxidation and contributes 2% efficiency of its device efficiency [1]. It was proper to have TBCs with PVD having ZrO_2-Y_2O_3 and NiCrAlY as ceramic and bond coats respectively which can introduce metal and ceramic grading between them that treats thermal expansion mismatch after 800˚C and also found that addition of 0.0127cm thickness would increase metal temperature which is highly undesirable [2]. 2D and 1D thermal model was developed by plasma sprayed ZrO_2-Y_2O_3 of cermet coatings such that bond coat and ceramic coat of 1st layer by low pressure plasma sprayed(LPPS) with 40% of ZrO_2-Y_2O_3 and another by air plasma sprayed(APS) with 33% of ZrO_2-Y_2O_3 in tubes and rods are obtained respectively with thickness of 0.001-0.003 inches thick and found that thermal conductivity of LPPS coatings was high than that of APS coatings [3]. The TBCs from EB-PVD of yttria partially stabilized zirconia possess thermal conductivity of about 1.8-2.0W/mK is nearly higher than PS coatings with thermal conductivity about 0.9-1.0W/mK, where the amount of dense zirconia of 8% helps to maintain thermal conductivity as low as 1.0W/mK. But introducing porosity in TBCs of PS is more suited than EB-PVD to lower thermal conductivity as EB-PVD results in different layers in TBCs which can maintain low thermal conductivity [4]. The TBCs of 1.2mm thick are achieved by laser drilling technique using Nd:YAG laser produced with bond coat of 0.15mm and ceramic top coat of 0.30mm thick respectively. The depth of hole was appeared to be 0.5mm diameter which was totally dependent on inclination of laser drilling angle of 30˚ and 45˚ [5]. Different composition powdered materials as 8% Y_2O_3–ZrO_2 and 25.5% CeO_2 and 2.5 Y_2O_3–ZrO_2 are used to coat TBCs by APS and LPPS to study change in TBCs properties due to the change chemical composition [6]. In finite element of proper periodic and symmetric boundary conditions with oxide thickness that formed around a bond coat protuberance after 200h at 1100˚C was developed. And showed that oxide thickness can leads to oxidation breakaway that is depletion of alumina features and also increased stresses due to surface roughness [7]. The coating of 3mm thick with bond coat(0.2mm) of hexaluminate of different material composition is obtained by plasma sprayed. Then thermal cycling test was conducted above room temperature till 1250˚C±30˚C for 5min and quenching for 2min with surface temperature of 970˚C±15˚C. The process is repeated until 5% of coating is lost and analysed through SEM [8]. Titanium alloy with density and thermal conductivity of about 3.183g/cm^3 and 2.0W/mK respectively is suited for its use in sandwich panels with thickness 0.102cm TBCs and core material is made of the same with thickness of 2.337cm is used to study about multifunctional TBCs in sandwich panels. Which resulted in proper and controlled heat transfer with high stiffness and strength [9]. TBCs like ZrO_2-Y_2O_3 having super alloys can be replaced ceramic composite materials(CMCs) due its low thermal conductivity, high efficiency and highly light weight in nature. And these CMCs can further have reinforced with silicon carbide (SiC) to develop crack tolerance. Since they possess good efficient thermal expansion coefficient and silicon was found to be an appropriate bond coat, CMCs can be employed in TBCs [10].

RESULTS AND DISCUSSIONS

GPX TBCs provides high precision, oxidation resistant and protects material either from heat or heat rejection mainly during firing. Its bond coat NiCrAlY with melting temperature about 2800˚F and bond strength of 8000psi and ceramic coat ZrO_2 with low thermal conductivity of about 1.3 W/mK are highly desirable factors [1].

PVD TBCs of thickness between 0.0127-0.0254cm is suited to increase coating durability and to limit metal temperature. But bond coat experiences phase transformation, creep, thermal expansion and oxidation where ceramic coat faces thickness, structure phase stability problems. Also adhesion issues between the coats. So in order to obtain durability these issues needs to be encountered [2].

According to 1D and 2D thermal models small variation in coating material composition can alter thermal conductivity even though with same thickness. Coated rods were durable than coated tubes when tested at 150-200˚C but same at ceramic/metal interface is lower in rods than tube at metal temperature at 145-160˚C. Lower deposition of temperature on rods results in smaller residual stress on rods which leads to greater TBCs durability than tubes [3].

It showed how different methods like PS and EB-PVD their dense composition can effect and influence thermal conductivity to be around 1.0W/mK and role of failure mechanisms which is necessary to make out depth of stress, cracks, creep in order to hold the durability [4].

Laser drilling technique showed that delamination cracks were observed with drilling at two angles 30˚ and 45˚ due high melting activity and also lead to increased damages mostly in leading edge when drilled more at acute angles to the surfaces. All these factors can in turn results in temperature gradients in TBCs [5].

The change in chemical composition of coating materials of plasma sprayed method results in different physical properties like colour change and thickness, and chemical property like chemical state is observed which reflects in reduced efficiency of TBCs [6]. The study of finite element oxide thickness that formed around a bond coat protuberance after 200h at 1100˚C resulted that alumina will grow till 0.003mm thick further oxidation breakaway happens results in fast growing non-protective oxides with stress development of about 25Mpa. Where out-of-plane stresses about 500Mpa appears due to non-uniformity in bond coat which can be avoided by cooling process to maintain TBCs [7].

It was found that the hexaluminates coatings from plasma sprayed resulted in weakened bond strength coatings and capable of inducing platelet like grain structures which promotes low thermal conductivity, large porosity, high sintering and strain resistant properties during thermal cycling [8].

It was demonstrated on titanium alloy and came to know that multifunctional TBCs can be used in sandwich panels which would control heat transfer and stiffness due to proper heat gradient that in turn enhances the stability of TBCs [9]. TBCs can be incorporated with CMCs instead of super alloys such that it results in improved efficiency, low thermal conductivity, desired thermal expansion and porous nature can provide high efficient and durable TBCs for aerospace application [10].

CONCLUSION

TBCs are well suited for aerospace application due to its high thermal resistant property. But its coating durability is mainly concerned with its methods used for deposition, phase transformation issues, material composition used in metallic bond coat and ceramic top coat, their thickness, their bond strength. Where methods like PVD, SP are suited for high temperature applications and GPX is used in heat transfer at firing. Material composition can be maintained like CMCs or super alloys based on application which can also result different coloured TBCs. And also the issues like oxidation breakaway can avoided by cooling method. All these can be incorporated to have durable, highly adherent and effective thermal barrier coatings.

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