Effect of Heat Treatment on Young’s Modulus and Poisson’s Ratio of Thermal Barrier Coating Studied by Bending of Three-Layered Specimen

by

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Thermal barrier coating (TBC) is a key technology for prolonging the life of the hot sections of gas turbine and airplane engines. A TBC system has a three-layered structure comprising a substrate, bond coat (BC), and TBC topcoat (TC). Young’s moduli and Poisson’s ratios of the coatings are important for calculating the parameters of material mechanics in the TBC system. However, research on Poisson’s ratio is scarce owing to the difficulty of its evaluation. The objective of this paper is to investigate the effect of high temperature exposure on Poisson’s ratios of yttria-stabilized zirconia TC and CoNiCrAlY BC. For this purpose, we evaluated the time-dependent Young’s moduli and Poisson’s ratios of coatings thermally treated at 600 °C to 1000 °C using the bending method. Our measurement revealed that an increase in Poisson’s ratios of the TC and BC as well as Young’s moduli depended on the temperature and length of exposure. The increasing rate in Poisson’s ratios was lower than that of Young’s moduli for both the TC and BC. These phenomena were explained by focusing on the microcracks and pores of the coatings.

Key words:

Thermal barrier coating, Elastic modulus, Sintering, Yttria-stabilized zirconia, MCrAlY, Four-point bending

1 Introduction

Thermal barrier coatings (TBCs) play a crucial role in the hot sections of gas turbine and airplane engines. They protect the underlying substrate from hot combustion gas by maintaining lower temperatures as a result of their low thermal conductivity. This leads to a more efficient turbine engine owing to the higher gas inlet and operating temperatures. A typical TBC system comprises a substrate, metallic bond coat (BC), and ceramic topcoat (TC), where MCrAlY alloys (M represents Co and/or Ni) and yttria-stabilized zirconia (YSZ) are used as BC and TC, respectively. The BC improves oxidation and corrosion resistance of the substrate, and the TC enhances the thermal insulation effect. In-service hot sections are subjected to thermomechanical loads as well as high temperature oxidation and corrosion. Hence, knowledge of Young’s modulus and Poisson’s ratio of TC and BC is necessary to design a high-performance TBC.

Heat treatment increases Young’s moduli of thermally sprayed MCrAlY and YSZ coatings owing to the sintering effect. It is known that the increasing rates highly depend on treatment temperature and length of exposure. This dependency has been investigated using an exponential function, Larson Millar parameters, and the time-dependent function with Arrhenius equation.

Research on Poisson’s ratio of MCrAlY and YSZ is limited because of the difficulty of its evaluation. Poisson’s ratio of heat-treated MCrAlY was examined using four-point bending and resonant ultrasound spectroscopy. Poisson’s ratio of YSZ was also evaluated, using the pulse-echo method. However, systematic research has not yet been conducted on the effect of heat treatment focusing on temperature and holding time.

Poisson’s ratio of thermally-sprayed coatings can be measured by bending a multilayered plate. We recently proposed a method to accurately determine Poisson’s ratio and Young’s modulus of the TC layer using the bending strain of a three-layered specimen coated on one side. In the report, we also analyzed the sensitivity of the method to experimental error using numerical and experimental approaches. We subsequently demonstrated that our proposed method is sensitive almost only to substrate properties, which can be measured precisely.

In this paper, we investigate the influence of high temperature exposure on Poisson’s ratios of TC and BC using the proposed method and comparing it with the effect on Young’s modulus. This paper targets CoNiCrAlY BC and YSZ TC deposited via atmospheric plasma spraying (APS). To investigate the effects of temperature and holding time, the time-dependent Young’s moduli and Poisson’s ratios of thermally treated (600 °C to 1000 °C) coatings were evaluated.
2 Method for Determining Young’s Modulus and Poisson’s Ratio of Thermal Barrier Coatings by Bending of Three-layered Specimen

We had proposed a method for determining Young’s modulus and Poisson’s ratio of TC accurately from the biaxial strains of a three-layered specimen coated on one side. The in-plane Young’s modulus and Poisson’s ratio of TC are obtainable from the in-plane force and moment balances.

We consider the three-layered model as shown in Fig. 1. The x-, y-, and z-directions are defined so that $z = 0$ is located at the interface between the substrate and the BC. Based on the laminated plate theory\(^{14,10}\), the force, $F$, and moment, $M$, balances in the x- and y-directions are given by Eqs. (1)–(4), where four-point bending is adopted (See Fig. 2).

$$\begin{align*}
F_x &= b \left[ \int_{-h_b}^{0} \sigma_{xx} dz + \int_{0}^{h_b} \sigma_{xy} dz + \int_{0}^{h_b} \sigma_{xz} dz \right] = 0 \quad (1) \\
M_x &= b \left[ \int_{-h_b}^{0} \sigma_{yx} dz + \int_{0}^{h_b} \sigma_{yy} dz + \int_{0}^{h_b} \sigma_{yz} dz \right] = \frac{Pa}{2} \quad (2) \\
F_y &= b \left[ \int_{-h_b}^{0} \sigma_{xy} dz + \int_{0}^{h_b} \sigma_{yx} dz + \int_{0}^{h_b} \sigma_{yz} dz \right] = 0 \quad (3) \\
M_y &= b \left[ \int_{-h_b}^{0} \sigma_{yx} dz + \int_{0}^{h_b} \sigma_{yy} dz + \int_{0}^{h_b} \sigma_{yz} dz \right] = 0 \quad (4)
\end{align*}$$

Here, $\sigma$ is the stress, $b$ is the specimen width, $h$ is the thickness of each layer, $a$ is the distance between the loading and supporting point, and $P$ is the applied load (See Fig. 2). The subscripts “s,” “b,” and “c” represent the substrate, bond coating, and ceramic top coating, respectively. When $P$ is applied as shown in Fig. 2, it is defined as a positive value.

The right-hand term of Eq. (2) indicates the moment generated by $P$.

The stresses in Eqs. (1)–(4) ($\sigma_x$ and $\sigma_y$) depend on the $z$-coordinate and so, using Hooke’s law, they can be expressed by the biaxial strains ($\varepsilon_x(z)$ and $\varepsilon_y(z)$). Considering the force balances given by Eqs. (1) and (3), $\varepsilon_x(z)$ and $\varepsilon_y(z)$ can be described using the strain of the coating surface\(^{10}\).

$$\Phi(\varepsilon_x, \varepsilon_y) = \left[ \frac{M_y - \frac{Pa}{2}}{L} \right]^2 + M_x^2 \quad (5)$$

Equations (1)–(4), with $h_c = 0$, represent the two-layered model consisting a substrate and BC (Fig. 3), allow for the evaluation of Young’s modulus and Poisson’s ratio of BC. Similarly Eq. (2), with $h_c = h_b = 0$, can be applied to the determination of Young’s modulus of a substrate using the uncoated substrate specimen. Poisson’s ratio of a substrate is directly obtained from the ratio of the biaxial strains of an uncoated substrate specimen.

We evaluate the elastic properties of a TBC in a...
step-by-step manner as follows: firstly, Young’s modulus and Poisson’s ratio of the substrate \( (E_s, \nu_s) \) are determined using an uncoated specimen. Young’s modulus and Poisson’s ratio of BC \( (E_b, \nu_b) \) are then obtained by bending the BC system specimen, where \( E_s \) and \( \nu_s \) needed for the calculations are known. Lastly, Young’s modulus and Poisson’s ratio of TC \( (E_c, \nu_c) \) are determined by conducting the bending test on the TBC system specimen. The measured \( E_s, \nu_s, E_b, \) and \( \nu_b \) are then used in the calculations. Thus, our proposed method provides \( E_s \) without using a freestanding coating.

### 3 Experimental Method

**3.1 Specimen**

The substrate used in this study was a Ni-based superalloy (Inconel alloy HX). The length of the substrate, \( L \), was 70 mm, the width, \( b \), was 10 mm, and the thickness, \( h_s \), was 2 mm. After blasting the substrate, the BC and TC were deposited via APS. The sprayed materials are CoNiCrAlY (Co-32Ni-21Cr-8Al-0.5Y, Amdry 9954 powder) and YSZ (ZrO2-8wt.%Y2O3, Metco204B-NS powder) for BC and TC, respectively. Details on the spraying conditions are listed in Table 1. The side surfaces of the specimens were polished to remove the coating deposited during spraying.

The apparent thicknesses of the layers for each specimen are presented in Table 2. The thicknesses used in the calculations were measured for the individual specimens. The width and substrate thickness were measured for each specimen using a micrometer. The thickness of each layer was obtained using scanning electron microscope (SEM) images of longitudinal sections of the specimens, where a field-emission SEM (JEOL JSM-7001F) was employed. A typical SEM image of the TBC system is shown in Fig. 4(a).

The heat treatment was performed at 600 °C, 800 °C, and 1000 °C using an electric furnace. The heating rate was 8 °C/min. The holding time at the maximum temperature ranged from 1 h to 75 h. Temperature holding was suspended at the appointed times and the specimens were cooled to room temperature in the furnace. Thereafter, the bending test of the specimen with heat treatment for the appointed holding time was performed. This sequential procedure was repeated until the total holding time reached 75 h. Two specimens were tested for each treatment temperature. Microstructures of the as-sprayed and heat-treated (1000 °C for 75 h) coatings were observed using SEM images of longitudinal sections of typical specimens, as displayed in Figs. 4(b)-(e). Here, it is confirmed that the crack is not induced by thermal treatment.

### 3.2 Method for Measuring Load and Strain

The loading span, \( a \), and the inner span, \( S \), denoted in Fig. 2, were 9 mm and 48 mm, respectively. In the case of specimen denoted in Section 3.1, these spans allow accurate

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**Table 1** Apparent thicknesses of the specimens (mm).

| Substrate | BC | TC |
|-----------|----|----|
| BC System | 2  | 0.3|— |
| TBC System| 2  | 0.15|0.5|

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**Table 2** Thicknesses of the specimens (mm).

| Equipment Metco F4 | Arc H2 (SLPM) | Arc Ar (SLPM) |
|--------------------|---------------|---------------|
| Powder Amdry 9954  | 130           | 120           |

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**Fig. 2** Images of a section obtained using SEM of (a) as-sprayed TBC system, (b) as-sprayed BC, (c) heat-treated BC at 1000 °C for 75 h, (d) as-sprayed TC, and (e) heat-treated TC at 1000 °C for 75 h.
evaluation owing to satisfying the ideal bending model. The \( v \) of the coating was under tension in the situation shown in Fig. 2. The specimen was inverted to obtain the compressive \( v \). An electro-hydraulic servo testing machine (Shimadzu, EHF-FB2kN-10LA) was used to apply the load, which was measured by a load cell with a capacity of 500 N (Kyowa Electronic Instruments, LUX-A-500N). The testing speed was 0.2 mm/min. The strain was measured using a biaxial strain gage with 1 mm gage length (Kyowa Electronic Instruments, KFGS-1-120-D16).

3.3 Method for Evaluating Residual Stress

Residual stresses of the TC and BC surface in \( x \)-direction were measured using X-ray diffraction through cos\( \alpha \) method at room temperature. The X-ray residual stress analyzer (Pulstec Industrial, \( \mu \)-X360) with Cr-K\( \alpha \) radiation was employed. X-ray conditions and X-ray elastic constants used in the calculation are shown in Table 3. The average stress was evaluated from five different locations for each specimen.

4 Results and Discussion

4.1 Load–Strain Relationship

Figure 5 shows the load–strain relationship of the TBC and BC system specimens, where the tensile \( \varepsilon_x \) occurs in the coating. It is known that the freestanding YSZ coating exhibits a strong inelasticity. By contrast, Fig. 5 shows the approximate linear relationship in the \( x \) and \( y \) directions for both as-sprayed and heat-treated TBC system specimens. The BC system specimen also exhibits a linear relationship. Note that the load–strain relationship exhibited relatively strong nonlinearity at first cycle, becoming stable after a few cycles.

The slope in \( x \)-direction, \( \Delta \varepsilon_x/\Delta \varepsilon_y \) and that in \( y \)-direction with the same \( \Delta \varepsilon_x \), \( \Delta \varepsilon_x/\Delta \varepsilon_y \), up to 200 microstrain on \( \varepsilon_x \) of coating were adopted for the calculations. The average value of three loading slopes obtained from the third to the fifth cycles, was used in the calculations for each specimen, where the slopes were determined by linear approximation.

4.2 Accuracy of Young’s Modulus and Poisson’s Ratio of Coatings

We discuss the accuracy of the evaluation method used in this paper. In this study, \( E_s \) and \( v_s \) were determined on an uncoated substrate specimen. The average \( E_s \) and \( v_s \) of the tensile and compressive directions were adopted because the difference was negligible: In this calculation, \( E_s = 191.5 \) GPa and \( v_s = 0.3095 \) were used as inputs. The determined \( E_s \) and \( v_s \) values are given in Table 4 together with the values of freestanding BC measured using the resonant ultrasound spectroscopy method. The materials used in Ref. 7 were identical to this study. Our measurements of \( E_s \) and \( v_s \) indicate acceptable agreement with previously reported values for both as-sprayed and heat-treated BC, thereby ensuring the reliability of our proposed method. Furthermore, we previously...
confirmed that $E_b$, $\nu_b$, $E_c$, and $\nu_c$ measured using our proposed method were consistent with values obtained by bending freestanding coatings\(^\text{(14)}\). It also indicates that $E$ and $\nu$ are not almost affected by curvature of the specimen.

Next, we consider residual stress in the coatings. It is known that large residual stresses cause inelastic behavior of YSZ by changing the shape of microcracks and pores\(^\text{(13, 19)}\). Room-temperature residual stress values of the YSZ coatings, measured using X-ray diffraction, are given in Table 5. Both the as-sprayed and heat-treated YSZ TC have comparable residual stress to the freestanding coating (approximately 3 MPa) at room temperature, as shown in Table 5: The residual stress remained low before and after heat treatment. Therefore, we concluded that the effect of the residual stress on TC is negligible in this study.

Finally, we discuss the residual-stress effect on the elastic properties of CoNiCrAlY BC. Table 5 indicates that heat treatment transforms high tensile residual stress of as-sprayed BC into compressive stress. On the other hand, the residual stress of freestanding coating was approximately 14 MPa: It was regarded as almost zero because the stress was lower than the standard deviation. By contrast, the $E_b$ and $\nu_b$ values of the as-sprayed BC system are similar to those of the as-sprayed freestanding coating as shown in Table 4: The BC is unaffected by residual stress. It means that the CoNiCrAlY coating exhibits high elasticity.

### 4.3 Effects of Heat Treatment on Poisson’s Ratio and Young’s Modulus of CoNiCrAlY Bond Coat

Figure 6 shows the $E_s$ and $\nu_s$ of the as-sprayed and heat-treated BCs under tension and compression. The input $E_s$ and $\nu_s$ values are determined in Sections 4.2. The average and standard deviation of six specimens are shown for as-sprayed BC. For thermally treated BC, the values are calculated from two specimens. The horizontal axis represents the root of total holding time. Figure 6 shows there are no differences in the values between tensile and compressive directions in BC.

Firstly, we discuss the effect of heat treatment on $E_s$. Heat treatment significantly increased $E_s$ as indicated in Fig. 6(a). The higher temperature enhances coating stiffness. Additionally, $E_s$ rapidly increases with the brief heat treatment (1 h) and shows little change with time thereafter. These behaviors agree with previous researches\(^\text{(3, 4)}\).

An increase in $E_s$ by heat treatment is attributed mainly to sintering of the BC\(^\text{(3, 4)}\). Our observation of the microstructure provides support for this view. The interface defects between the splat particles are partially reduced by heat treatment, as indicated in Figs. 4(b) and (c). Densification is a possible factor for the enhancement of coating stiffness due to sintering\(^\text{(3)}\). Further, for sintered BC, the mutual bonding between splat particle and $\text{Al}_2\text{O}_3$ oxide with high stiffness contributes to an increase in $E_s$\(^\text{(3)}\).

Secondly, we consider $\nu_s$, whose increase rate depends on the treatment temperature as indicated in Fig. 6(b). The increase in $\nu_s$ at 600 °C is lower than those at 800 °C and 1000 °C. Further, $\nu_s$ increases significantly with heat treatment for 1 h. Therefore, the value at 600 °C increases slightly and those at 800 °C and 1000 °C remains constant with an increase in treatment time, respectively. Sintering of the BC also explains an increase in $\nu_s$ similar to $E_s$.

We then compared the increased $E_s$ and $\nu_s$. The $E_s$, with heat treatment for 75 h, is higher than the as-sprayed $E_s$ by 73% (600 °C)–102% (1000 °C). The average value of $\nu_s$, thermally treated at 600 °C to 1000 °C for 75 h, is higher than the as-sprayed $\nu_s$ by 27%. The lower increasing ratio of $\nu_s$ is attributed to the small difference in $\nu$ between the as-sprayed and

### Table 5 Residual stresses in CoNiCrAlY BC (APS) and yttria stabilized zirconia TC (APS) evaluated using X-ray diffraction (MPa).

|       | As-sprayed | 1000°C, 2 h |
|-------|------------|-------------|
| BC    | 130        | -174        |
| TC    | 26         | 25          |
coating and bulk material. The $E_b$ and $\nu_b$ of as-sprayed BC are approximately 46% and 66% of those of the bulk CrCoNi material (approximately 235 GPa\(^{20}\)) and 0.31\(^{20}\)) the composition of which is similar to CoNiCrAlY. The greater increase in $E_b$ of the thermal spray coating is also as a result of the difference between Young’s modulus of CoNiCrAlY and Al\(_2\)O\(_3\) oxide. The $E_b$ of the coating is enhanced by the mutual bonding between splat particle and Al\(_2\)O\(_3\) with high stiffness (approximately 400 GPa\(^{11}\)), whereas the presence of Al\(_2\)O\(_3\) has little influence on $\nu_b$ of the coating because Poisson’s ratio of Al\(_2\)O\(_3\) (approximately 0.24\(^{11}\)) is low and similar to that of the heat-treated CoNiCrAlY.

4.4 Effects of Heat Treatment on Poisson’s Ratio and Young’s Modulus of YSZ Topcoat

The $E_c$ and $\nu_c$ of YSZ TC were evaluated on the TBC system specimen. The input $E_c$ and $\nu_c$ values are determined in Sections 4.2. The as-sprayed and thermally treated $E_b$ and $\nu_b$ shown in Fig. 6 were used. We adopted the average $E_b$ and $\nu_b$ of the tensile and compressive directions. Figure 7 shows the averaged $E_c$ and $\nu_c$ of the as-sprayed and heat-treated TCs, and standard deviations. The number of specimens used in calculation is the same as the BC. The horizontal axis denotes the root of the total holding time. Note that insignificant differences in the tensile and compressive values are indicated in Fig. 7 as similar to BC.

Firstly, we discuss the effect of the heat treatment on $E_c$. As indicated in Fig. 7(a), the heat treatment at 600 °C has no effect on $E_c$. By contrast, $E_c$ increases with the heat treatment at 800 °C and 1000 °C, and the enhancement is significant at higher temperature. The $E_c$ also sharply increases with the first treatment (1 h). The dependencies on treatment temperature and time are consistent with previous researches\(^{8-13}\).

Sintering is considered as the main factor for increasing $E_c$ with heat treatment\(^{8-11, 13}\). It was previously reported that the enhancement of $E_c$ of as-sprayed YSZs by heat treatment occurred at a temperature higher than 819 °C\(^{13}\). Figs. 4(d) and (e) provide evidence for reduction in microcracks and pores in TC after heat treatment. The porosity measured using SEM images of longitudinal sections through a thresholding technique was 10.3% for as-sprayed TC and 8.5% for thermally-treated TC (1000 °C for 75 h).

Concerning $\nu_c$, similar temperature- and time-dependencies to $E_c$ are observed as indicated in Fig. 7(b): $\nu_c$ rapidly increases during the first treatment (1 h) and then rises slightly as the treatment progresses. This time dependency is similar to that previously reported for the heat treatment effect of up to 1400 °C on as-sprayed YSZ\(^{10}\). An increase in $\nu_c$ with heat treatment results from a sintering\(^{10}\).

Finally, the increases in $E_c$ and $\nu_c$ are then compared. The $E_c$ values, with a heat treatment at 800 °C–1000 °C for 75 h, are 54%–155% higher than the as-sprayed $E_b$, respectively. Meanwhile, the $\nu_c$ with a heat treatment at 800 °C–1000 °C for 75 h, are greater than the as-sprayed $\nu_b$ by 23%–75%, respectively. The lower increasing ratio of $\nu_c$ results from a smaller difference in $\nu$ between the as-sprayed coating and the bulk material. The differences in $E_c$ and $\nu_c$ between as-sprayed TC and YSZ fine ceramic\(^{22}\) are approximately 16% and 29%, respectively.

4.5 Fitting of Temperature- and Time-dependent Young’s Moduli in the Topcoat and Bond Coat

To investigate the dependency on $E_b$ and $E_c$ on heat treatment, we fitted the measurements to a time-dependent function including Arrhenius equation. Both the tensile and compressive Young’s moduli were fitted without distinction because the direction-dependent difference was insignificant, as described in Sections 4.3 and 4.4. The ratio $\Delta E_b/E_b, _\lambda_n$, where $E_b, _\lambda_n$ denotes $E_b$ of as-sprayed BC, was proportional to the $n$-th power of the holding time, $t$, for a treatment temperature ranging from 600 °C to 1000 °C. Therefore,
\( \Delta E_0/E_{A\alpha} \) can be described by Eq. (6).

\[
\frac{\Delta E}{E_{A\alpha}} = k^n
\]  

(6)

Here, \( k \) is the rate constant of \( \Delta E/E_{A\alpha} \) at different temperatures and is estimated by Arrhenius equation given in Eq. (7).

\[
k = k_0 \exp \left( -\frac{Q}{RT} \right)
\]  

(7)

Here, \( k_0 \) is the constant factor, \( Q \) is the activation energy, \( R \) is the general gas constant, and \( T \) is the treatment temperature. Equations (6) and (7) are also applicable to the ratio \( \Delta E_0/E_{A\alpha} \), except in the case of heating at 600 °C. Figures 6(a) and 7(a) display the fitted curves. Young’s modulus can be estimated using the time-dependent function with Arrhenius equation for both BC and TC. Note that Eq. (6) is inapplicable to \( v_s \) and \( v_c \) because they are almost independent of the holding time as shown in Figs. 6(b) and 7(b).

The obtained \( Q \) and rate exponent, \( n \) values are listed in Table 6. Previously, \( n \) was estimated to be 0.2 from the results for YSZ TC thermally treated at 1500 °C (11). Also, for \( Q \), the previous study determined 93.6 kJ/mol using YSZ TC thermally treated at approximately 1088 °C to 1349 °C (13). These values correspond to our results. Further, the previously reported \( Q \) of sintering volume change (98 kJ/mol) was corresponded to our results: This provides the evidence that the increase in \( E_s \) was caused by sintering.

In this paper, the obtained \( n \) of TC is higher than that of BC, meaning that the holding time dependency of TC is stronger than that of BC. As for \( Q \), our value for BC is lower than that for TC, revealing that TC shows the weaker treatment temperature dependency compared to BC.

5 Conclusions

The effect of high temperature exposure on Poisson’s ratios of YSZ TC and CoNiCrAlY BC was investigated by bending a three-layered specimen. We also compared the effects of high temperature exposure on Poisson’s ratio and Young’s modulus. Young’s moduli of YSZ and CoNiCrAlY were estimated using the time-dependent function including Arrhenius equation. The following results were obtained.

Table 6 Obtained activation energy, \( Q \), and rate exponent, \( n \), of CoNiCrAlY BC and YSZ TC.

|        | \( Q \) (kJ/mol) | \( n \)  |
|--------|------------------|--------|
| BC     | 8.1              | 0.061  |
| TC     | 67.7             | 0.222  |

(1) The residual stress in CoNiCrAlY BC transformed from high tension to compression by heat treatment. The stress effect on inelasticity was negligible as the inelasticity of BC was weak. In the case of YSZ TC, the residual stress remained low before and after heat treatment. The low stress had an insignificant effect on the relatively strong inelastic property.

(2) Young’s modulus and Poisson’s ratio of CoNiCrAlY BC increased by the heat treatment that ranged from 600 °C to 1000 °C. The higher treatment temperature had a greater effect on the enhancement of Young’s modulus. As for Poisson’s ratio, the dependency on the treatment temperature was insignificant. Young’s modulus and Poisson’s ratio of the as-sprayed CoNiCrAlY rapidly increased during the first treatment (1 h) and then rose slightly as the treatment progressed. The increase in Poisson’s ratio was lower than that of Young’s modulus because of the small difference in Poisson’s ratio between the as-sprayed coating and the bulk material. We concluded that the enhancement of Young’s modulus and Poisson’s ratio was caused by sintering.

(3) Young’s modulus and Poisson’s ratio of YSZ TC increased by the heat treatment at 800 °C or more, the temperature of which was higher than that for CoNiCrAlY BC. Young’s modulus and Poisson’s ratio increased as the treatment temperature rose. The time-dependency of Young’s modulus and Poisson’s ratio of the YSZ was similar to that of CoNiCrAlY. The increased ratio indicated a similar relationship to CoNiCrAlY, which is attributed to the difference between the as-sprayed coating and bulk ceramic. We concluded that an increase in Young’s modulus and Poisson’s ratio of YSZ occurred by sintering.

(4) Young’s moduli of YSZ TC and CoNiCrAlY BC depended on the treatment temperature and holding time. Thus, Young’s moduli were estimated using the time-dependent function with Arrhenius equation. Our quantitative evaluation showed that the holding time dependency of YSZ was stronger than that of CoNiCrAlY, whereas the treatment temperature dependency of YSZ was weaker than that of CoNiCrAlY.

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