Measurement on the thermal barrier ability of ceramic coatings in a flame thermal shock tester

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Abstract: Ceramic materials are widely used at high temperatures due to their low thermal conductivity. Thermal barrier coatings (TBCs) have been applied in hot sections in industrial gas turbines and air engines. The measurement of the thermal barrier ability of the TBCs is very important for coating property evaluation, that can be done in hot gases with temperature gradient through the coatings. In this study, a flame thermal shock tester was used for such investigation. Thick TBC, containing a MCrAlY bond coat and a YSZ top coat, was sprayed onto a superalloy substrate by air plasma spray (APS) process. In the test, hot flame impacted on the top coat surface with the temperature controlled by an infrared thermometer. A thermocouple was attached onto the backside of the substrate to measure the backside temperature. Therefore, the temperature gradient in the TBC can be evaluated. The thermal barrier ability of the TBCs in different back cooling rate was studied.

1. Introduction
Thermal barrier coatings (TBCs) have been widely used to protect the component in gas turbines [1-3]. Many studies have been carried out on the thermal shock fatigue behavior of TBCs using various testing conditions [4-6]. By using flame as the heating source and using forced air to cool the samples is a better approach for thermal shock testing of coatings like TBCs as such process does not bring water corrosion effect for the edge cracking [7,8]. To test coatings’ ability against thermal cycling spallation, controlling of the surface temperature is important, including not only the holding (operation) temperature but also the heating rate (start up of the engine) and cooling rate (shut down) [8]. In this study, the thermal barrier ability of the TBCs in different back cooling rate was studied by using a flame thermal shock tester.

2. Experimental
GH4169 superalloy with diameter of 25.4 mm was used as substrate and a MCrAlY as bond coat. A ~350um thick yttria stabilized zirconia (YSZ) TBC coating was made by APS process in a GTV spraying system. The APS TBC coating had about 10~15% porosity. Thermal shock testing of the TBC samples was performed in aflame thermal shock platform (made by Beijing QinheTechnol.company, China). A propane/oxygen flame gun was fixed on a mechanical moving system with a CCD camera for recording the coating surface and a infrared thermometer for monitoring the temperature. More description of the
testing machine can be found in [8,11]. The flow rate of propane and oxygen gases was a constant in each testing trial. As shown in figure 1, hot gases attacked the TBC surface with cooling air at back side of the sample. At the back side, a hole was drilled so a thermocouple can measure the temperature near blew the TBC coating.

Figure 1. (a) schematic drawing of sample, (b) front side of TBC sample, (c) back side of TBC sample with a drilled back hole.

Table 1 gives the flow rate of gases in different testing trails of flame thermal shock. Every trail contained a single thermal cycle with fixing propane and oxygen flow rate. By changing the oxygen flow rate among the trails, the surface temperature of TBC sample can be changed. By changing the back cooling flow rate of forced air, the temperature of the sample backside can be obtained. The working distance (gun to sample) was about 30mm.

Table 1. Parameters in testing trails of flame thermal shock.

| Trails | Propane flow rate, L/min | Oxygen flow rate, L/min | Back cooling flow rate, L/min |
|--------|--------------------------|-------------------------|-----------------------------|
| 1#     | 12                       | 17                      | 10                          |
| 2#     | 12                       | 18                      | 10                          |
| 3#     | 12                       | 20                      | 10                          |
| 4#     | 12                       | 20                      | 30                          |
| 5#     | 12                       | 20                      | 50                          |
| 6#     | 12                       | 17                      | 10                          |

3. Results and Discussion
In trail 1#, oxygen flow rate of 17 L/min was used and back cooling air of 10L/min. As given in figure 2, the temperature of the TBC surface was recorded. After about 200s, the temperature of the sample center (location A) was almost stable at around 1030 °C. At about 230s, the infrared thermometer was moved to measure location B and the temperature became around 980 °C. So about 50 °C difference was shown. Further measuring location C and D, the temperature of the sample edge was about 20 °C lower than the center.
Figure 2. Temperature recording result at the front surface in trial 1#, to measure the temperature variance at sample surface.

In trial 2#, the temperature of the front and back sides of the samples was recorded simultaneously with oxygen rate 18 L/min and back air 10 L/min. The back temperature was measured in the back hole. At beginning of the heating process, the temperature of the front side increased faster, so the temperature difference between the front and back sides was high. With the following-up of the back temperature, the difference became smaller. After about 200s, the measured temperature at front and back sides became the same. It indicated that with a low back cooling rate, the TBC coating can provide little thermal barrier effect.

Figure 3. Temperature recording results in trial 2#.

Figure 4 compares the results using different back cooling rates. The temperature difference at 200s was <10 °C with 10 L/min of back cooling and 10 °C with 30 L/min. With 50 L/min of back cooling, the temperature difference can get to 20 °C after 300s when front temperature reach 1150 °C. So, the thermal barrier ability of TBC coatings had a strong relationship with the back cooling. A larger cooling rate gave larger temperature gradient by TBC coatings.

Figure 4. Temperature recording results in trial (a) 3#, (b) 4# and (c) 5#.

In trial 6#, the thermocouple was firstly attached to the back surface of the sample. A large temperature difference (about 300 °C) was obtained. Such value, however, can not reflect the real temperature of the sample because the cooling air took away too much heat from the thermocouple. When put the thermocouple into the back hole, the temperature difference became small. It indicate that to measure the temperature at the backside of the sample by using thermocouple, a drilled hole to set the thermocouple was necessary. In addition, by changing the oxygen flowing rate, the heating rate of the...
TBC can be changed (from ~400 ºC to 1000 ºC), which gives a large space to perform various experimental testings.

Figure 5. Temperature recording results in trial 6#.

Figure 6. Heating time to 1000 ºC (front side) by changing oxygen rate.

4. Conclusions
A flame thermal shock tester was used to measure the thermal barrier ability of a TBC sample with a back hole. The temperature difference between the coating surface and the back hole can be obtained. The main conclusions are:

1) With a low back cooling rate (< 10L/min), the TBC can hardly give a thermal barrier effect. An enough high back cooling force was necessary to reflect TBC’s thermal barrier ability.
2) By increasing the back cooling rate to 50L/min, the TBC coating gave about 20 ºC decrease at 1150 ºC.

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