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Effect of periodic in situ deposition of silica layer on the long term operation of a micro-gas turbine

Min Tae Kim *, Doo Soo Kim

Power Generation Laboratory, Korea Electric Power Research Institute, Daejeon 305-308, Republic of Korea

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ABSTRACT

Tetraethylorthosilicate (TEOS) diluted in methanol was periodically supplied during operation of a 13 kg*f* (max. thrust)-class small gas turbine to deposit silica layers on the turbine blades and its effect on the degradation of the turbine blades upon the long term cyclic operation (1 cycle: 30/10 min run/pause at 20,000 rpm) was tested. The exhaust gas temperature (EGT) was set at 800 °C. For comparison, two other gas turbines were also tested without feeding TEOS at the EGT of 800 °C and 700 °C, respectively. The blades were inspected optically and metallographically before and after the test. The supply of TEOS produced a white silica layer indicating a very low level of the apparent density all around the surface of the blades, some of which became dense at the end to a thickness of 5–10 μm. The underlying substrate Inconel 713 was effectively protected, while the blades operated at the EGT of 800 °C, but not in situ coated, were severely degraded in terms of the surface oxidation and microstructural evolution of the substrate. The microstructure of the protected substrate was comparable with that of the unprotected but operated at the EGT of 700 °C. This result was discussed based on the effect of the formation of dense silica layer on the blade by comparing with the previously obtained results.

1. Introduction

Ever increasing demands for high thermal efficiency is triggering the development of gas turbines being operated at higher temperatures (combustion temperature, or turbine inlet temperature, TIT) than ever, which needs sophisticated component design (e.g., cooling holes in the blades [1,2]) and high temperature materials (e.g., nickel base single crystal superalloy [3–5] and thermal barrier coatings, TBC [6–8]). As a consequence, almost all the researches to date have devoted to develop designs and materials applicable at the fabrication stage of gas turbines to meet these demands.

A coating technology applicable to gas turbine systems during service, not at the stage of fabrication, was proposed and studied recently [9–12]. This in situ deposition method allowed to obtaining oxide based protective coatings on the surface of all the components in contact with hot gas during service. In those previous works [10–12], TEOS was utilized as film precursor to deposit silica based oxides on the components.

According to a very short term test on turbine blades made of a carbon steel, SM45C, a marked increase in the component durability to more than 10 times at the EGT of ~750 °C was noticed due to the in situ deposition [9]. Moreover, in situ deposited silica coatings gave excellent protection for Inconel 713 superalloy blades not only during service, but during ex situ cyclic oxidation tests [10–12]. These results were attributed partly to thermal insulation of the outer layer with a high porosity ~80% [10] and partly to diffusion inhabitation of the inner thin solid layer. The microstructure of the coatings was able to be controlled to some extent by regulating the input rate of film precursor [11,12]. However, yet to be tested is the influence of the coatings on the long term operation of the gas turbine, which is the subject of this work.

2. Experimental procedure

Three sets of axial type 13 kg_f-class micro gas turbines were tested in a total of 120 cycles, in which one cycle was composed of 30 min steady run plus 10 min pause. One gas turbine was operated with the periodic addition of TEOS to an amount of 0.5 wt.% to fuel, LPG (liquid petroleum gas) at the EGT of 800 °C. TEOS diluted in methanol (10 vol.%) was fed steadily at room temperature at every 10th cycle including the first cycle to the fuel line through an extra pipeline just ahead of the gas inlet into the combustion chamber [10]. Inconel 713 turbine blades are supposed

Table 1
Operation conditions applied to the three gas turbines.

Applied condition	TEOS, wt.%	EGT °C	No. of cycles	rpm
C1	0.5	800	120	20,000
C2	–	800	59	20,000
C3	–	700	120	20,000

* Corresponding author. Tel.: +82 42 865 5681; fax: +82 42 865 5365.
E-mail addresses: mtkim@kepri.re.kr, jasmint@paran.com (M.T. Kim).

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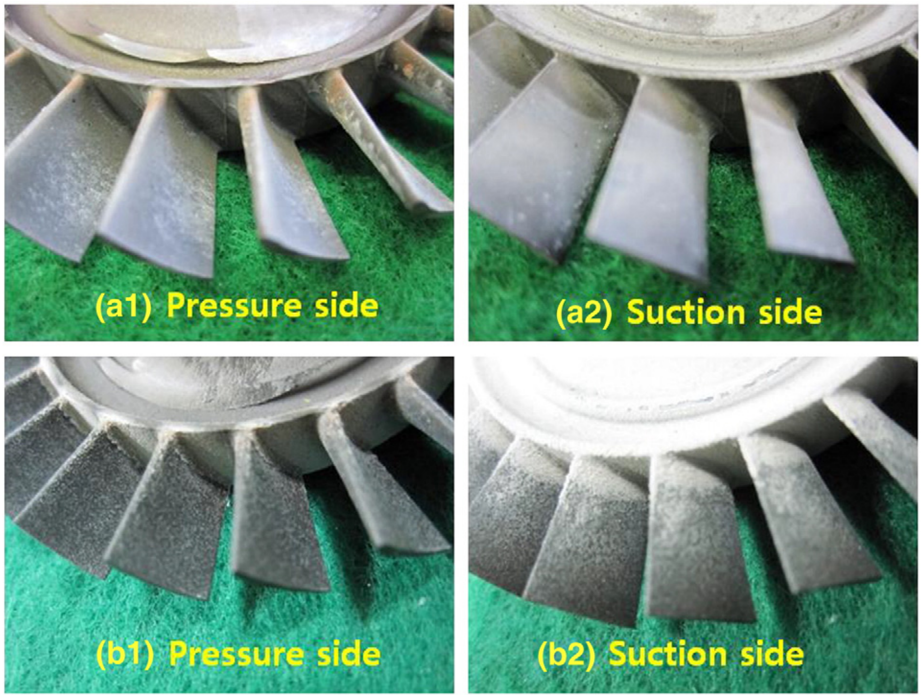

Fig. 1. Macro-images of the C1 blades after (a) 30 cycles and (b) 120 cycles.

to be coated in situ with silica-based layers by burning TEOS with fuel during operation, as reported in the previous works [10,11]. Two other gas turbines were operated without feeding film precursor at the EGT of 800 and 700 °C, respectively. The three test conditions were summarized in Table 1.

The influence of in situ deposition of silica on the long term cyclic operation of gas turbines was evaluated by analyzing the surface oxides and the metallographic evolution of the blade substrate, Inconel 713. Surface images were taken using a digital camera and a scanning electron microscope (SEM, Jeol). Energy-dispersive X-ray (EDX) measurements were also made for the identification of the surface oxide. Cross-sections of the blades were metallograpically etched for revealing the microstructure of the blades before and after the test.

3. Experimental results and discussion

Fig. 1 shows macro-images of the C1 turbine blades under testing (30 cycles, Fig. 1a) and after the test (120 cycles, Fig. 1b), respectively.

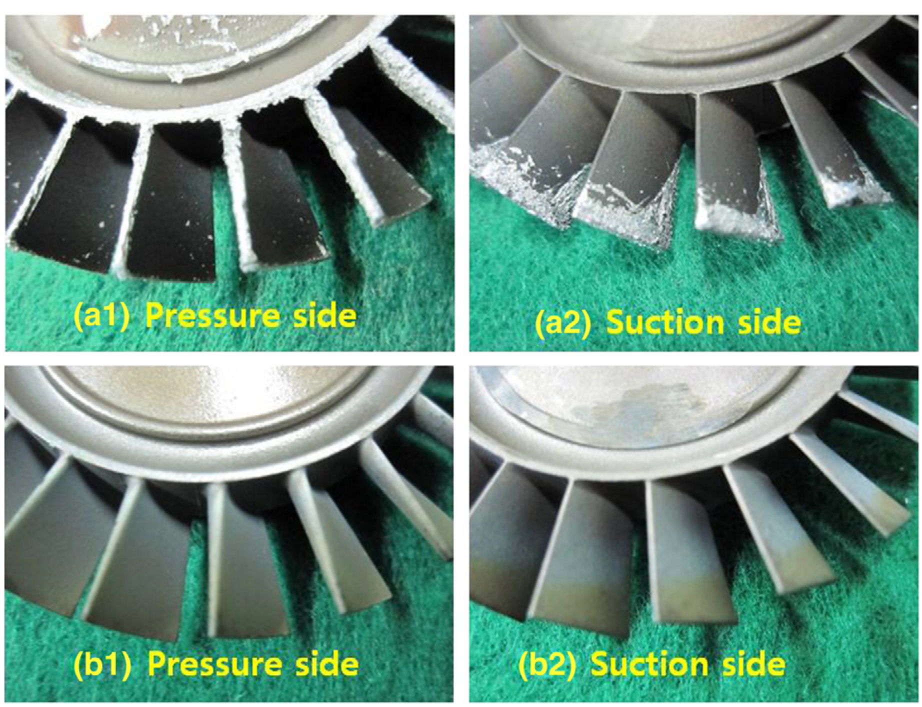

Fig. 2. Macro-images of (a) the C2 blades after 59 cycles and (b) the C3 blades after 120 cycles.