RESEARCH ON APPLICATION OF CERAMIC TURBINE TO JET ENGINE

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Abstract

In recent years, turbine inlet temperature becomes higher and higher to grow up the power of gas turbine engines. The hot section parts, such as combustor and turbine, are generally designed as cooling structures which were made of heat resistant metals. However, some organizations research and develop the ceramics parts as next generation materials instead of heat resistant steels. A key technology for this system is the thrust growth of the jet engine without increasing the outer dimensions. For that purpose, turbine inlet temperature must be increased and a ceramic turbine was considered as the most superior choice since air cooled metal turbine is too complicated and expensive. This paper describes the current achievement of the research of the ceramic turbine jet engine. In this study, the ceramic turbine is applied in the aircraft gas turbine engine and the engine testing is demonstrated under full load operating conditions. The successful testing of the ceramic turbine components in the aircraft gas turbine engine has been accomplished.

1 Introduction

The turbine inlet temperature becomes higher and higher to grow up the power of gas turbine engines in recent years. So hot section parts, such as combustor and turbine, are generally designed as cooling structures made of heat resistant metals, and some organizations research and develop the ceramics parts as next generation materials instead of heat resistant steels[1][2].

The purpose of this research is thrust growth of jet engine without increasing the outer diameter dimensions, so turbine inlet temperature must be increased. For that higher turbine inlet temperature, turbine nozzle is air cooled metal airfoils and turbine blade is ceramic turbine wheel with blade since air cooled metal blades is too complicated and expensive.

This paper describes the outline of the research of the ceramic turbine jet engine initiated in 1997.

2 Jet Engine Configuration

The type of this jet engine is most simple single spool turbo jet engine. Figure 1 shows the ceramic turbine jet engine configuration. The main parts consist of combined compressor of single axial type and single centrifugal type, annular type combustor with spray type and single axial turbine, and ceramic turbine wheel is adopted. Turbine nozzle material is heat resistant steel, so that has air cooled airfoils with film cooling holes and so on.

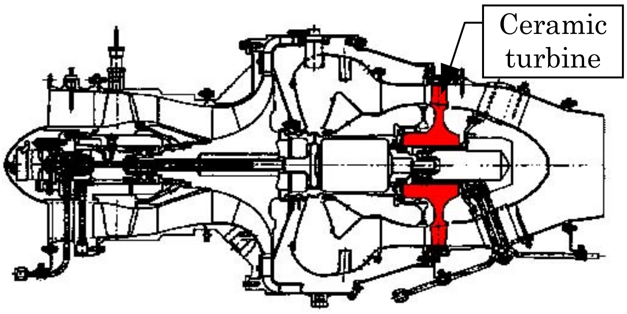


Fig. 1 Schematic of ceramic turbine engine

3 Design of Ceramic Turbine

The main parameter of ceramic turbine is shown in Table 1. Silicon nitride (Si_3N_4) was adopted as design material because of its higher strength in high temperature

3.1 Material Test

Various material tests ware carried out to get the basic material data for the design. At first, test pieces ware cut out from the wheel in Fig. 2 and 4 points bending test was carried out. The cut out positions of these test pieces ware bore position (near inner diameter of wheel) and neck position (most thin position of wheel). And the test pieces of neck position ware two kind of surface conditions, as machined and as fired. Because the wheel surface sections as machined must be reduced for the cost down and the data of test piece as fired must be needed.

Table 1 Main parameter of ceramic turbine

Item	Value
Material	Si_3N_4
Tip diameter	ϕ 218mm
Rotational speed	490m/s(Tip speed)
Inlet temperature	1,100℃
Inlet Pressure	1.030kPa
Power	1,900kW

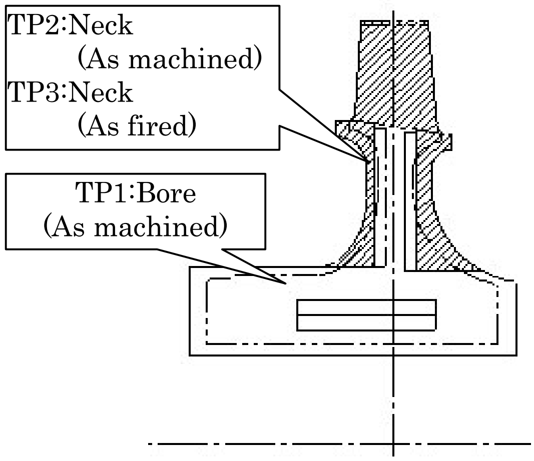


Fig. 2 Cut out position of test pieces

Figures 3 and 4 indicate the bending test results at room temperature and at 1100℃, respectively. The ordinate denotes the failure probability based on Weibull distribution. As shown in Figs. 3 and 4, the strength of test piece as fired was as same as that of original design

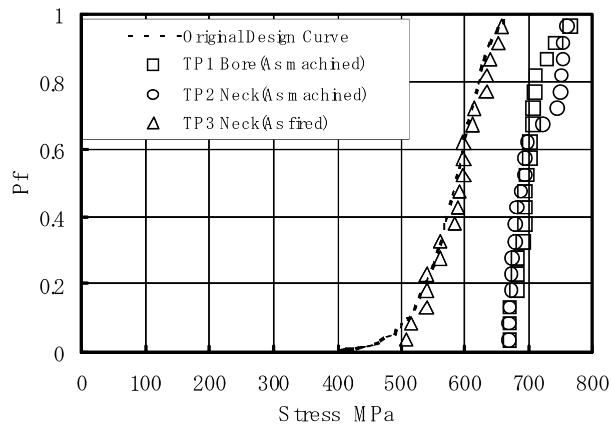


Fig. 3 Bending test results (room temperature)

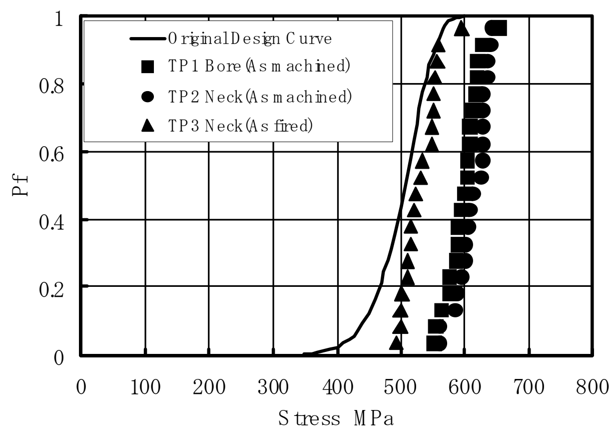


Fig. 4 Bending test results (1100℃)

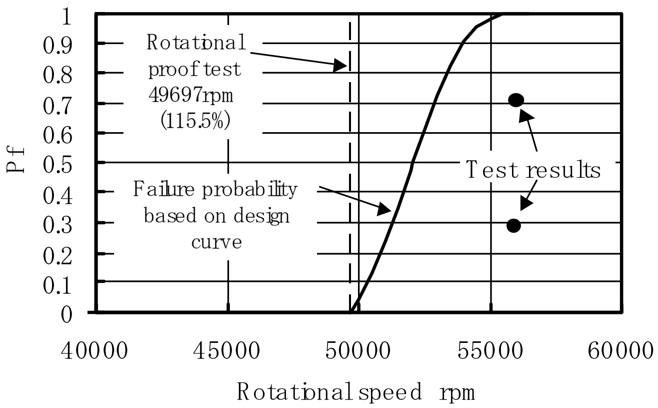


Fig. 5 Rotational test (room temperature)

curve, and that of test piece as machined had nothing to do with the cut out position and was stronger than that of original design curve.

From these results, the new design curve of ceramic turbine was decided as follows, the surface strength was as same as that of test piece as fired and the inner strength was as same as that of test piece as machined.

In order to confirm the failing rotational speed, rotational test for the ceramic turbine wheel was carried out under the room temperature condition. Figure 5 shows the results of rotational test. It is seen from Fig. 5 that the failure probability curve based on design has the sufficient margin to the test results.

3.2 Design of Connected Section

The subject of application of ceramic turbine is the way to connect the ceramic turbine and rotational shaft. Thermal expansion ratio of ceramic is lower than that of metal alloys and so the difference of thermal expansion between a ceramic part and a metal alloy part is occurred. Ceramic is brittle material and weak in the peak stress by the stress concentration. Therefore, it is difficult that ceramic turbine is directly fixed with the rotational shaft. The metal flange with low thermal expansion is fixed with the ceramic turbine by shrinkage fit method, and ceramic turbine is fixed with rotational shaft by using that flange. Figure 6 shows the structure of

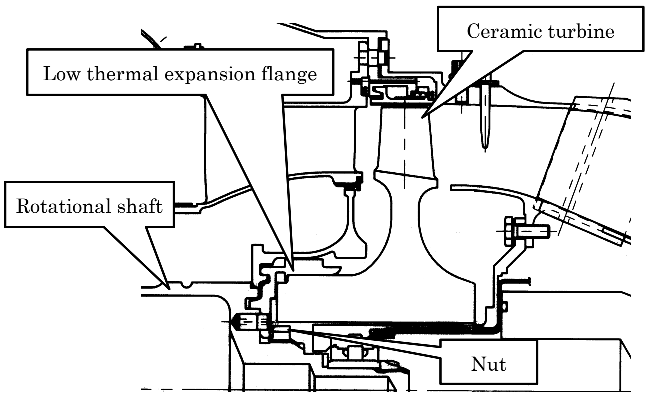


Fig. 6 Structure of connection of ceramic turbine and rotational shaft

connection of ceramic turbine and rotational shaft in the test engine.

The tight force of this shrinkage fit section was confirmed by the preliminary simple model test. The outline of the simple model test is shown in Fig. 7. The metal flange is fixed with the ceramic test piece which has the same dimension of shrinkage fit section as the ceramic turbine by shrinkage fit method. Then 10 same models were produced and the constrain force dispersion was confirmed by measuring the each constrain force. The method of this test was followings; heated up to 500℃ more than the used temperature, and fixed the metal flange, and

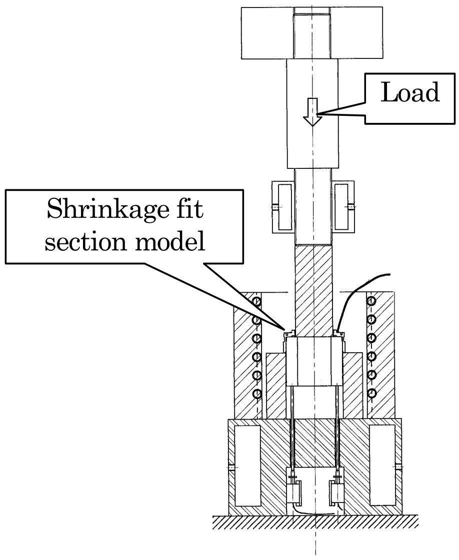


Fig.7 Simple model test setup

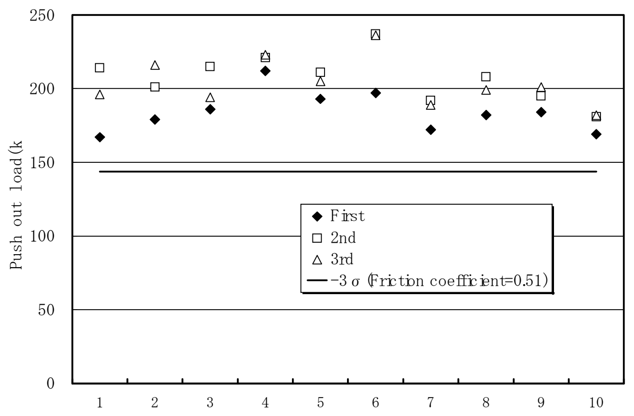


Fig. 8 Results of simple model test

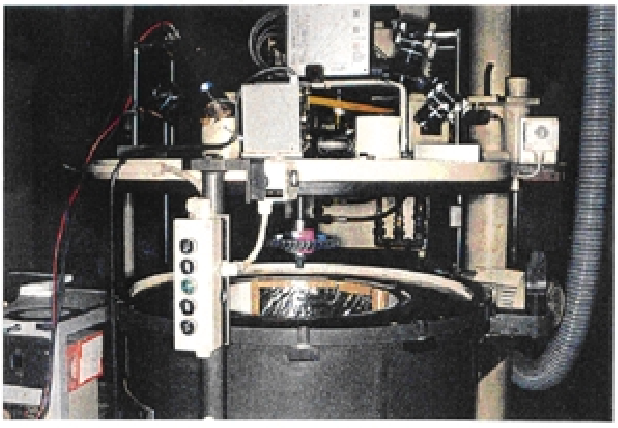
added the load against ceramic. The load was added three times against the same model and the load to pull out ceramic was measured. The test results are shown in Fig. 8. The structural reliability of the shrinkage fit section is confirmed by the simple model test under the high temperature condition (500℃). Furthermore, the standard design load corresponding to -3 σ was estimated by the test results.

4 Proof Test of Ceramic Turbine

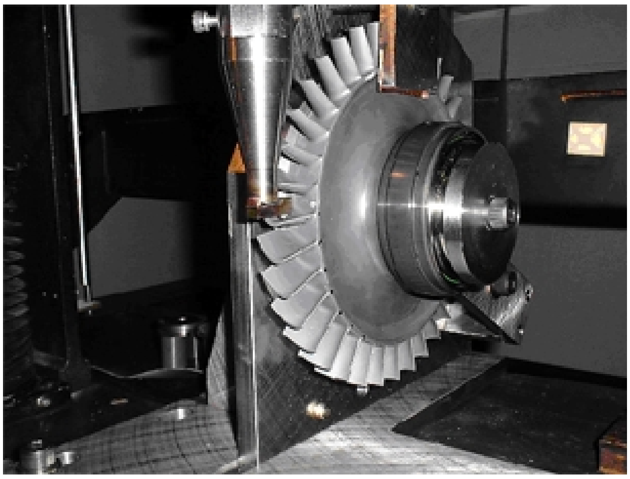
As the characteristics of ceramic, ceramic has a tendency to increasing the defects in proportion to its volume, and it has possibility to be broken by the small defect which is not found by Non Destructive Inspection (NDI), since ceramic is fragile material. Therefore, for proof of ceramic products, it is indispensable to screening by adding the load to ceramic turbine. This ceramic turbine is rotational part, so basic proof test is rotational test. In addition, for the proof test of blades, blade bending test was carried out. Figure 9 shows the proof test setup.

5 Engine Test

Ceramic turbine manufactured with using these design concepts was applied to the engine test. Engine test is started from Sea Level Static (SLS) condition test, and test condition gradually stepped up. Finally engine test was carried out under the condition of compressed



(a) Rotational test



(b) Blade bending test

Fig. 9 Proof test setup

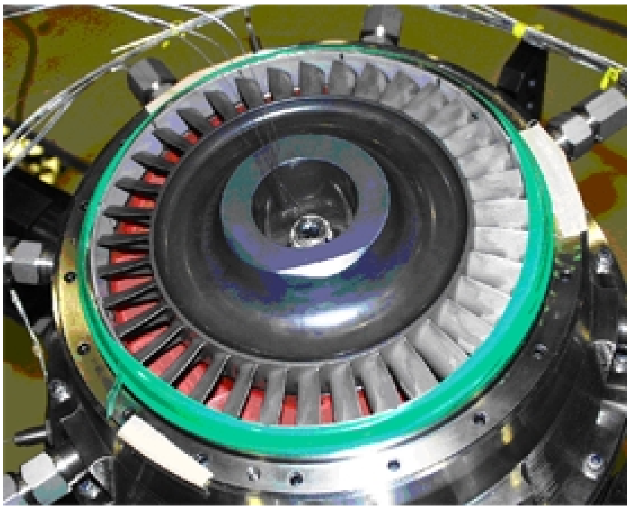


Fig. 10 Ceramic turbine in the engine

Fig. 11 Engine test setup

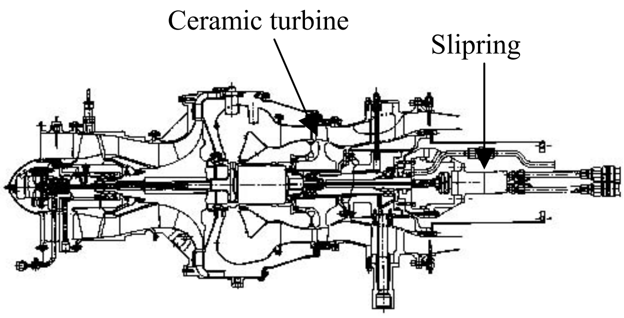


Fig.12 Schismatic of onrotor type engine with slipring

inlet air as the flight mach number. Test engine configuration was two types, normal type jet engine and onrotor type engine with the slip ring to measure the temperature on shrinkage fit section of ceramic turbine in the engine operation. The ceramic turbine setup in the engine and the engine test (under flight condition) setup are shown in Figs 10 and 11, respectively. Schematic of the onrotor type engine with slipring is shown in Fig. 12.

Figure 13 shows the results of engine test. The test results indicate the ceramic turbine is capable of operating under the condition of fast starting to full speed. Table 2 shows the temperature of shrinkage fit section in operating the engine. It is seen form Table 2 that the measured temperature and the estimated temperature under flight condition are less than the allowable temperature respectively.

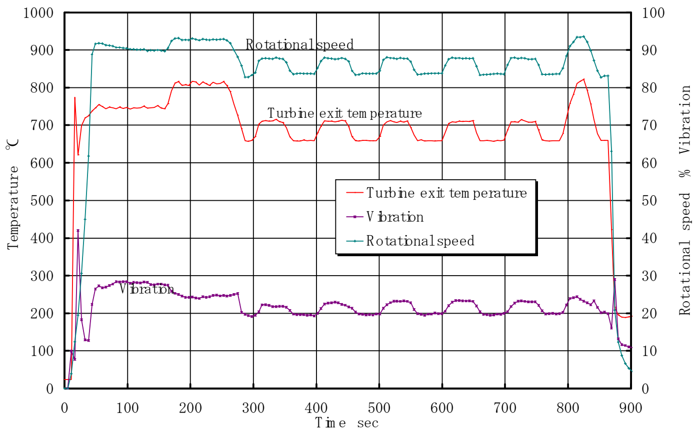


Fig. 13 Results of engine test

Table 2 Temperature of shrinkage fit section

	Engine Speed rpm (%)	Measured Temperature ℃	Estimated Temperature ℃	Allowable Temperature ℃
Sea Level Static Condition	36550(85) 40000(93)	240 316	- -	569
Flight Condition	43000(100)	-	441	

6 Conclusions

In this study, the ceramic turbine is applied in the aircraft gas turbine engine. The structural reliability of ceramic turbine component in the aircraft gas turbine engine has been confirmed by the engine test with the engine performance based on design. The result of this study has got a prospect of application of ceramic turbine to jet engine.

In the future study, higher structural reliability of the ceramic turbine is needed to the actual use of the ceramic turbine jet engines.

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