FABRICATION OF
TITANIUM METAL MATRIX COMPOSITE BLING

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SUMMERY: Metal matrix composite (MMC) bling (bladed ring) for gas-turbine's compressor was developed. The bling was consist of monolithic titanium clad and hoop reinforced MMC core. The MMC core material was using titanium matrix coated fiber. The MMC core's fabrication process included winding of matrix coated fiber (wire) to pre-form and hot press consolidation of stacked pre-forms. The clad and the core were integrated into one piece ring with HIP. The results shows this process can minimize the misalignment and fiber breakage during consolidation. Uniform wire diameter, precise winding, and hot pressing are effective for successful processing. The burst spin strength of bling achieved 89% of coupon tensile strength.

KEYWORDS: Metal Matrix Composite, Titanium Alloys, Bling, Ring, Hoop Reinforcement, Gas-generator, Rotor, Processing, Hot Press, HIP, Spin Test

INTRODUCTION

Research Institute of Advanced Material Gas-generator (AMG) aims to establish basic key technologies for the next generation gas turbine using advanced materials such as composites and intermetalic compound, which should have the feature of significantly low fuel consumption with reduced weight and size, and should be environmentally acceptable, toward the realization of future industrial marine and aerospace gas-turbine [1].

High efficiency and high performance compressor for future gas-turbine requires higher rotating speed and lower weight than the compressor with conventional heavy disks and blades. Due to their high specific properties and high temperature capability, continuous fiber reinforced titanium metal matrix composites (MMC) are attractive compressor material [2][3].

Although a number of fabrication methods to achieve ring or disk shape of titanium MMCs have been developed [4], much efforts must be necessary to optimize fabrication technique. Some papers describe matrix coated fiber process is a one of the best way to achieve the ring or the bling (bladed ring) with less risk of fiber breaking during consolidation than other processes[4][5][6]. It is because the reinforcing fiber is pre-coated with the matrix alloy and the volume change during consolidation is smaller than other processes. However, little work is currently available in the published literature on the ring fabrication with its quality and strength.

This study outlines MMC bling fabrication with the matrix coated fiber process and describes the key factor of fabrication. To describe the bling quality and property, microstructure observation and non destructive inspection were conducted, and burst spin test was also carried out.

MMC BLING MODEL

The fabricated MMC bling geometry was shown in Fig.1, 212mm in outer diameter and 140mm in inner diameter, 19mm in thickness, and it has 15mm blade length. The all rings include 170-150mm in diameter and 13mm in thickness MMC core. The MMC core ring was reinforced with fibers only in hoop direction. The geometry was derived from basic stress calculation in order to achieve burst at MMC area within the maximum hoop strength.

MATERIAL

The clad material of the bling was Ti-6Al-4V. The core material was SiC/Ti-6Al-4V. In this study we used the matrix coated fiber process to fabricate the core. This process uses pre-coated fibers called as the titanium matrix composite (TMC) wires, supplied by 3M, 0.240mm diameter. They are Ti-6Al-4V EB-PVD[7] coated on 0.140mm diameter silicon carbide fibers (SCS-6) supplied by Textron Systems. Its volume fraction of fiber in each wire is 35%.

DEVELOPMENT OF FABRICATION PROCESS

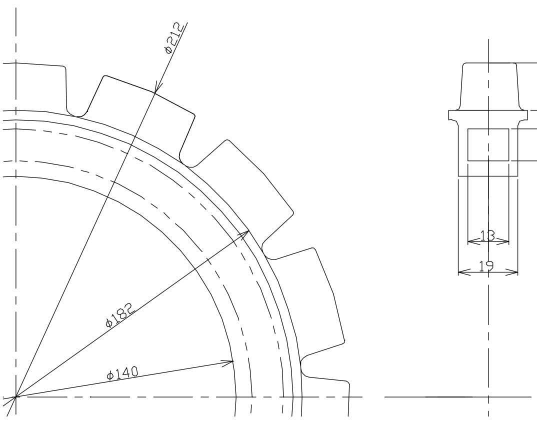


Fig.1 MMC bling model

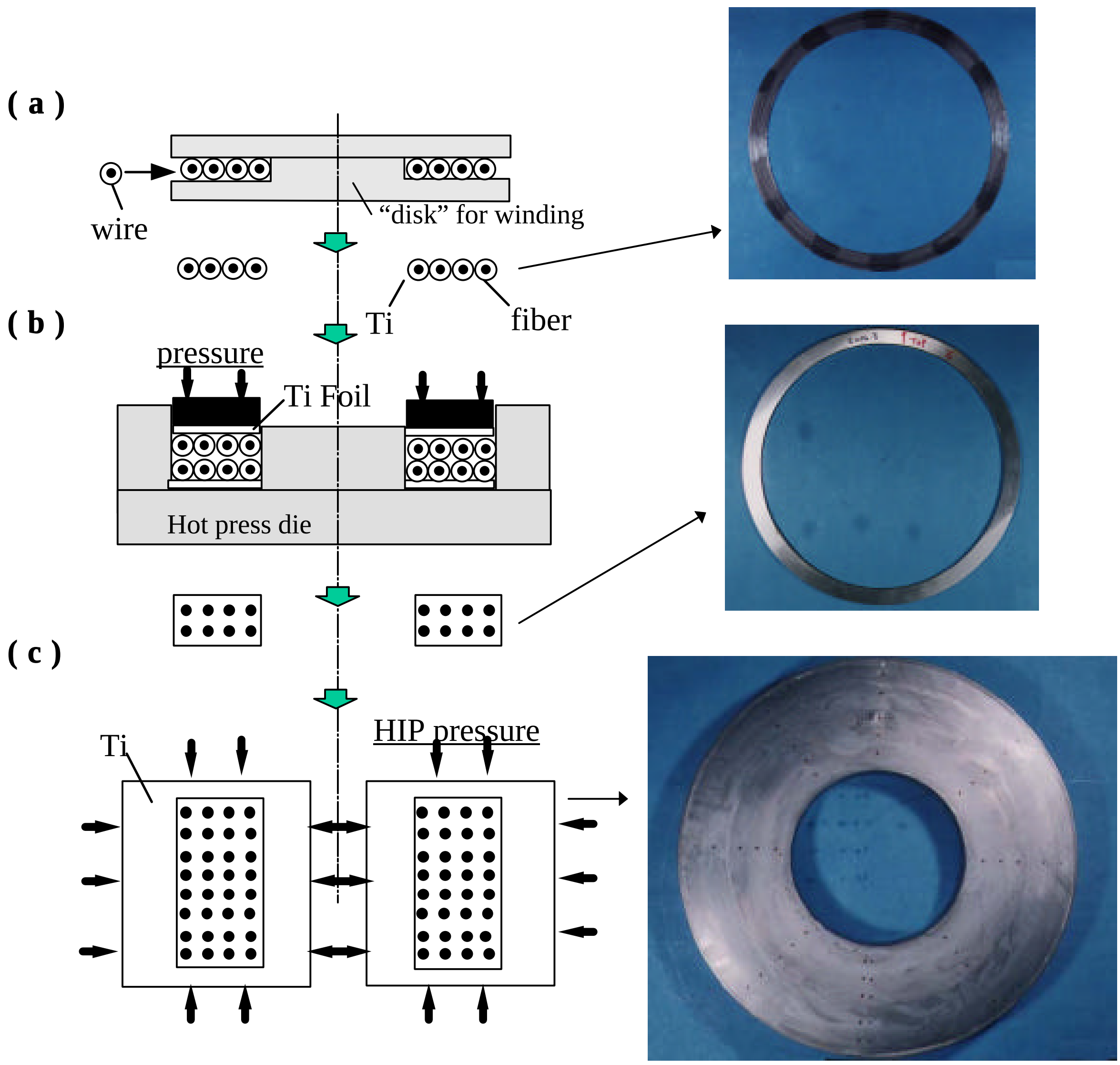
The fabrication process was based on the previous study [8], illustrated in Fig.2. This process included two step consolidation, hot press followed by HIP. Details are described as follows.

Pre-forming of ring with wire winding

A continuous TMC wire was wound in hoop direction between a clearance of two disk shaped winding tooling and the wound wire was kept in ring shape with adhesive. It was a pre-form which thickness was same to the wire diameter (Fig.2 (a)) Precise winding was required to achieve good fiber distribution after consolidation and preventing fiber breakage. The winding machine setting was optimized to realize the precise winding.

Hot Press consolidation of pre-forms

The plural of pre-forms were stacked between a couple of ply of titanium foils and consolidated with hot press. The fiber movement during consolidation could be influenced by the construction of the hot press die and the direction of the applied pressure load. For that reason, the clearance between the diameter of hot press die and that of the pre-forms were designed to be minimized. The hot press condition was 800°C, 20MPa for 3Hrs. Each of the hot pressed MMC rings had about 3 mm thickness (Fig.2 (b)). Four individual MMC rings were pressed and shaped for the size available to insert into the titanium ring. After consolidation the ring were machined to the designed dimensions and inspected by X-ray radiography to describe the fiber alignment and defect indication.



(a) pre-form winding, (b) hot press , (c) HIP

Fig.2 MMC bling fabrication process

HIP diffusion bonding of the titanium clad and the MMC rings

The MMC rings were stacked and embedded in the combination of Ti-6Al-4V clad ring, encapsulated in a steel capsule, out gassed, closed by welding and then hot isostatic pressed (HIP). The size of Ti-6Al-4V clad ring was designed in order to apply pressure load parallel to the center axis of the ring to prevent radial fiber movement during HIP. The HIP condition is 800°C, 140MPa for 3Hrs. After consolidation the HIP'd ring was machined to the rough dimensions and inspected by using X-ray radiography to check de-lamination and defect indication in the MMC core and titanium clad.

Machining

The bling was machined to the designed shape with condition which could minimize transformation caused by stress release induced during consolidation.

Consolidation condition

The hot press and HIP consolidation condition in this study were derived from (1) the relationship between fiber-matrix reaction layer thickness generated by thermal history, (2) fiber alignment and residual porosity within consolidate ring.

Firstly, the TMC wire were cut into several pieces and then they were heat treated at several temperatures and time in vacuum. The range was 750°C- 900°C, 0.5-9Hr. And their fiber-matrix reaction layer thickness were measured by cross section microstructure observation. The relationship between the heat treated condition and reaction layer thickness was predicted using Arrhenius type relation (Fig.3)[9]. Since our two step consolidation process requires longer heat history than usual process, the consolidation temperature should be lower than usual condition , 900°C.

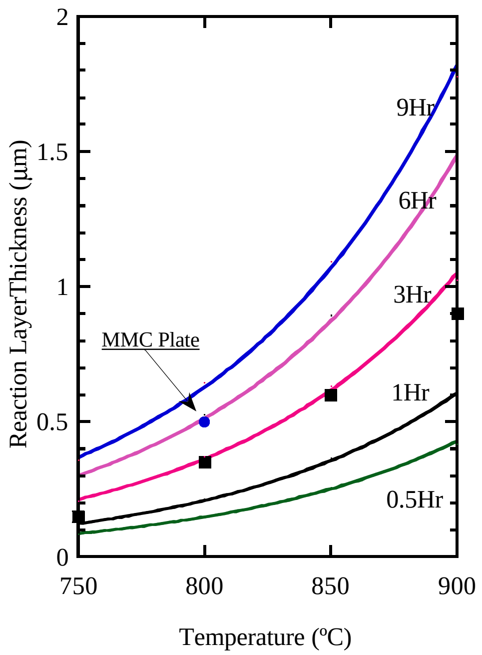


Fig.3 Predicted fiber-matrix reaction layer thickness

On the other hand, the consolidation requires higher pressure in low temperature. In this study, the consolidation pressure was determined by ring consolidation trial and the others study [10].

Finally, coupon specimens (UD, Vf=28%) were fabricated in the selected condition, and they exhibited 1684MPa (UTS) and 199GPa (modulus) in average. They had approximately 0.5 micrometer reaction layer thickness. As the result, we confirmed the selected condition was enough to consolidate in minimum porosity and without harmful fiber damage.

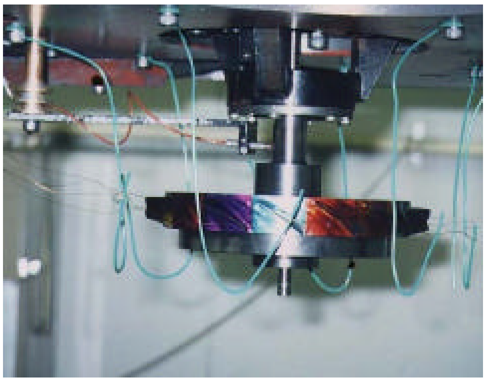


Fig.4 MMC bling assembled in test fixture

Spin test Procedure

Burst spin test of the MMC bling was conducted to certify the strength. The test was carried out with a facility having air turbine in a vacuum chamber. The test ring was attached to a drive shaft shown in Fig.4. The rotation speed and vibration of the shaft are recorded up to the burst speed.

FABRICATED BLING EVALUATION

Fabricated Ring

Fig.5 shows the appearance of fabricated MMC bling. The X-ray radiographic photograph of hot pressed rings and the final shape bling in Fig.6 present precise positions of fibers and no fiber breakage or buckling indications. And MMC position in the clad was matched to the design requirement (Fig. 7). The cross section microstructure at the MMC portion (Fig.8 (a)) indicates good fiber distribution. The TMC wire diameter distribution effects to the fiber distribution in the matrix. The fiber matrix reaction layer thickness was around 0.5 micrometer (Fig.8.(b)) which was good agreement with the value predicted in Fig.3. The titanium matrix microstructure in the MMC core is very fine compared with the titanium clad microstructure (Fig.8(c)).

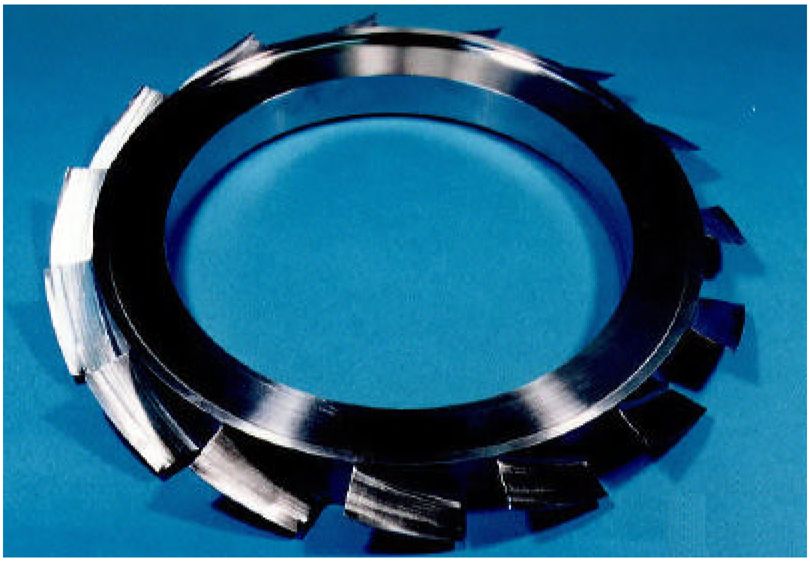


Fig5 Appearances of MMC bling

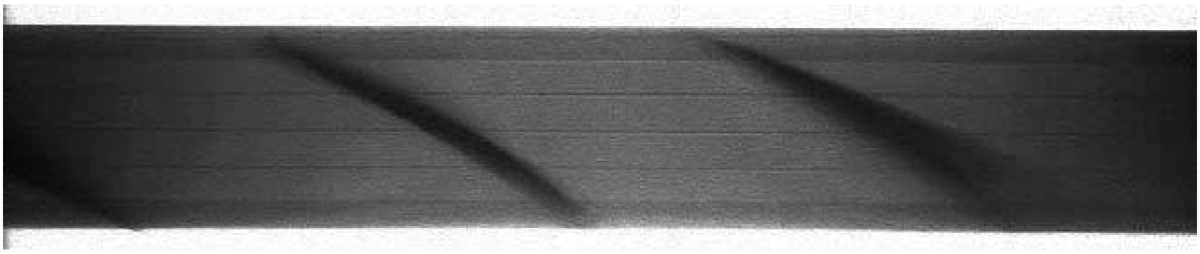


Fig.6 X-ray radiographic photograph

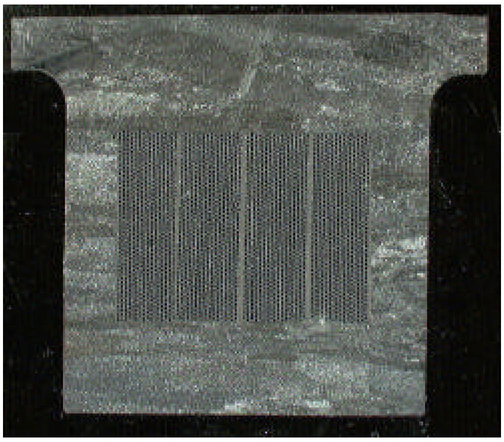
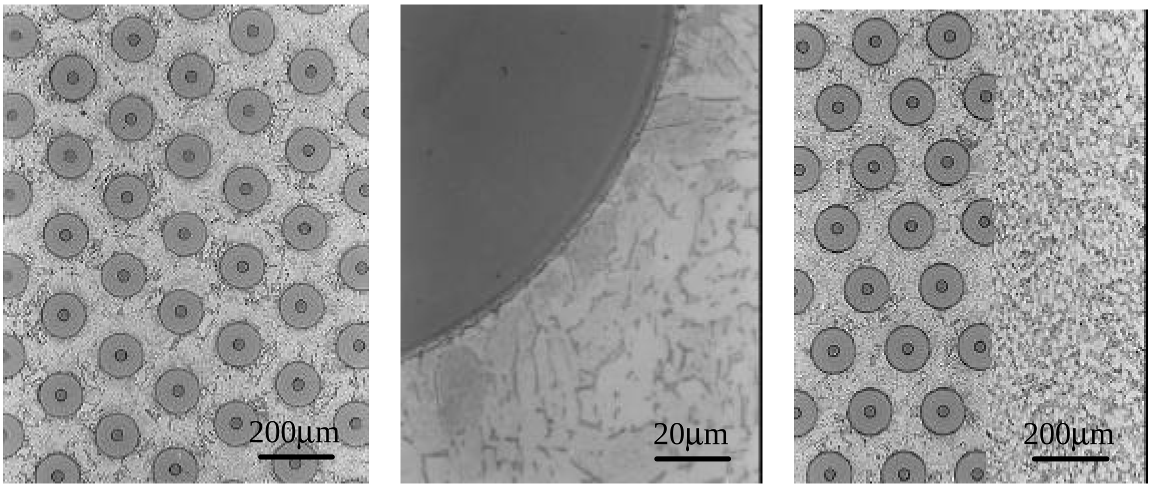


Fig.7 Bling macrostructure

Fig.9 MMC bling after burst.



(a) (b) (c)

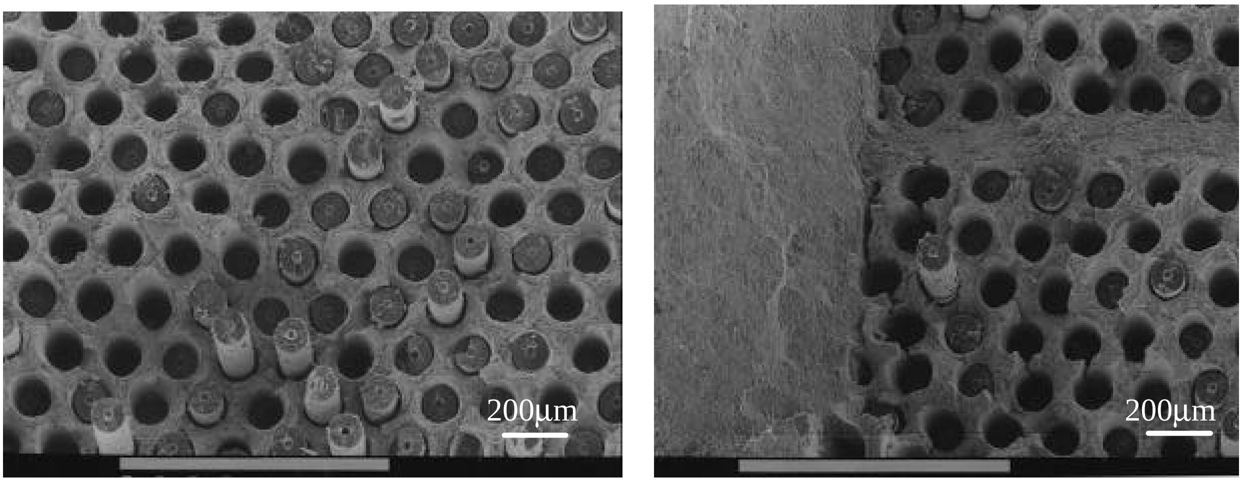
(a) (b)the MMC core area, (c) the core and titanium clad interface area

Fig.8 MMC micro structure

Post-Spin test Evaluation

The bling after burst is shown in Fig.9 . The bling burst into six groups at 55830rpm. The blade tip speed reached to 619m/s. The AMG target performance (570m/s) was achieved. The primary failure was due to the tensile overload in the hoop direction, and secondary fracture were supposed to be flexural fracture under centrifugal forces. Most pieces were damaged by colliding with the containment. The primary fracture surface indicates ductile flat fracture from tensile overload. (Fig.10 (a)). It indicates MMC hoop direction failure. And the MMC core was partially de-laminated from the titanium clad after the burst (Fig.10(b)).

Maximum stress of the bling by FEM estimation was 1678MPa at the bore of the MMC core. This result indicated the MMC exhibited 89% tensile strength of the same volume fraction (33%) coupon specimen.



(a)the MMC core (b) interface area of the clad and the core

Fig.10 Primary fracture surface of MMC bling

DISCUSSION

From the results in this study, it may be concluded that the bling achieved desirable quality and property. The advantages of this process are as follows. (1) Homogeneous TMC wires diameter prevents the defects or fiber breakage. The winding machine is necessary to realize uniform wire tension for achieving precise winding to avoid a pre-form shape distortion. (2)Using hot press is effective to minimize the fiber movement and fiber breakage. The radial direction stress caused inside the ring can be limited by uni-directional pressing, and minimum clearance between the pre-forms and the press dies. (3)Well selected consolidation condition is also important. Adequate condition can allow matrix flow without fiber breakage and result in good fiber alignment, and also it can prevent properties degradation by excessive fiber-matrix reaction.

It must be emphasized that it is possible to consolidate MMC in 800°C which is lower temperature than the general temperature in fiber-foil-fiber processes. It is because PVD pre-form can decrease the process temperature due to its fine grain size. These structure enhances the superplastic behavior of the alloy and it can deform in lower temperature than forged foil [10]. However, de-lamination at the interface between the clad and the core is of concern . It means there is insufficient diffusion bonding at the area, it is possible to initiate crack under the cyclic loading by mechanical or thermal. HIP diffusion bonding condition must be optimized under the consideration of titanium clad properties. Much more consolidation condition developments are required to enhance the properties of MMC bling.

CONCLUSION

Metal Matrix Composite (MMC) bling was fabricated with the matrix coated fiber and two step consolidation. The quality and the property of the bling was evaluated with microstructure observation, non-destructive inspection and burst spin test. The main results obtained are shown below.

(1) This process can minimize the misalignment and fiber breakage during consolidation.

(2) Especially, uniform wire diameter, precise winding, and hot pressing are effective for successful processing.

(3) The burst spin strength of bling achieved 89% of MMC coupon tensile strength. It shows this process can exhibit expected strength.

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