TITANIUM METAL MATRIX COMPOSITE DEVELOPMENT FOR COMMERCIAL AIRCRAFT LANDING GEAR STRUCTURE

Norio TAKAHASHI*, Toyohiro SATO*, Shinichi Nakatsuka*, Kouta Fujiwara*, Keisuke YOSHIDA** and Tomohiro Yokozeki**
* Sumitomo Precision Products Co., Ltd.
**The University of Tokyo, Graduate School of Engineering,
(E-mail: takah-no@spp.co.jp, yokozeki@aastr.t.u-tokyo.ac.jp)

Keywords: *TiMMC, Landing Gear Structure, FOD, NDI, Weight Reduction*

Abstract

We have developed a prototype Titanium Metal Matrix Composite (TiMMC) Landing Gear Components as a potential replacement for Ultra-High Strength Steel (300M) Components and have achieved a 30% reduction in weight, and mitigated the risk of corrosion and in-service problems associated with 300M.

This paper describes the design, manufacturing and test methodologies for a prototype TiMMC Component - "Side Stay".

We will show the structural integrity benefits of TiMMC Landing Gear Components, including FOD characteristics, weight reduction and structural attributes for future lighter weight and high rigidity components to apply in Landing Gear Structure design and manufacture.

1 General Introduction

Through our Landing Gear design and development experiences, we have used Ultra-high Strength Steel 300M[1]. However, if the 300M component is not designed, manufactured, and processed properly, corrosion and/or fatigue problem may occur in-service. In addition, because the corrosion environment cannot be perfectly simulated during Qualification Tests, the corrosion mitigation processes cannot be correctly and qualitatively evaluated.. We cannot accurately evaluate either corrosion acceleration or corrosion problems which differ due to aircraft operation, maintenance action and actual environment operator-by-operator.

When severe corrosion or fatigue problems occur, costly maintenance action, such as the replacement and/or repair of the component will be requested by the operators. In order to avoid these problems, we started to develop a New Material to replace 300M and simultaneously reduce the risk of corrosion and fatigue problems in the field. In this paper, we will describe the newly developed material as our solution for lighter weight and corrosion resistance for Landing Gear Components as follows;

- Polymer Matrix Composite
- Metal Matrix Composite

2 Polymer Matrix Composite Study

For Landing Gear Structural Applications we initially studied Carbon Fibre Reinforced Plastic (CFRP). In the case of Landing Gear Structural Components, Pin joints are required to assemble Landing Gear and attach it to the airframe. From our calculation, a very thick CFRP plate is required to fabricate the Pin joint areas. So, two types of test were conducted to evaluate the suitability of CFRP in Landing Gear components - one is CAI (Compression After Impact) Test and the other is Bearing Test for the Pin Joint.

The following three type of CFRP Test Plate were fabricated by RTM (Resin Transfer Molding);

(1) Quasi-isotropic
(2) Anisotropic
(3) Z-axis + quasi-isotropic

2.1 CAI Test[2]

Table 1 shows the Test Panel Conditions for CAI Test.

Table 1 CAI Test Condition

CFRP Condition	No. of TP
Number of TP	4 or 5
TP Size	50 X 100 X 10t mm
Fibre	Toray T800-24K
Resin	KIC = 1.07MPa・$m^{1/2}$
Impact Energy	67Joule per JIS K 7089

Fig. 1 shows the UT Inspection results for Quasi-isotropic TP after impact. Upper slides show the impact side and lower slides show the rear face side. As shown in Fig. 1, damage was found in the rear face, and no visual damage was found in either side surface. Fig. 2 shows the CAI Test results.

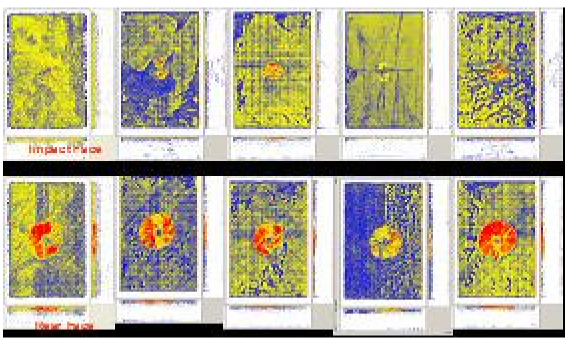

Fig. 1 UT Inspection Results for Quasi-isotropic TP After Impact

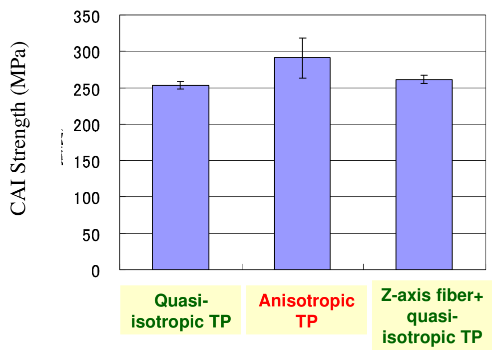

Fig. 2 CAI Test Results

2.2 Bearing Test for Pin Joint

We conducted a bearing test for the pin joint. Test results are shown in Fig. 3.

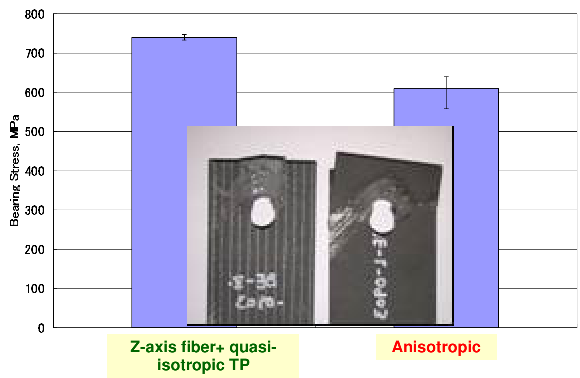

Fig. 3 Bearing Test for Pin Joint

From the CAI Test and Bearing Test of 10 mm thick CFRP, we identified the following issues to be solved in order to apply to Landing Gear Parts;

- It is difficult to detect damage during the operations.
- Material strength is less than or equal to High Strength Aluminum Alloy.
- Bearing strength is less than or equal to High Strength Aluminum Alloy.

As our conclusion, it would be necessary to increase the Bearing Strength of CFRP and at the same time, decrease the Pin diameter of the Joint areas in order to apply CFRP to Landing Gear structural applications.

3 Metal Matrix Composite

3.1 Design Specifications of Side Stay

We studied Titanium Metal Matrix Composite (TiMMC) for Landing Gear Components. From the CFRP experimental studies, as shown in Para.2, we need to increase the Bearing Strength in order to reduce the PIN diameter. TiMMC's have a metal strength greater than Aluminum Alloy if 6Al-4Va titanium alloy is used. Table 2 shows the material properties of TiMMC;

Table 2 TiMMC Material Properties

Material Condition	No. of TP
Fibre	Silicon Carbide
Fibre Sterength	3200 MPa
Fibre Stiffness	330 GPa
Monolithic 6-4Ti Strength	935 MPa
Monolithic 6-4 Ti Stiffness	105 GPa

Side Stay consists of a hybrid structure of Titanium Matrix Composite and monolithic Titanium metal as shown in Fig. 5. The Cylindrical Section is TiMMC. The Lug Sections (both clevis ends) are monolithic Titanium metal. Titanium metal basically uses 6-4 Titanium alloy.

In order to study the TiMMC Landing Gear components, we selected the Side Stay because of the simple tension and compression of the side stay component in the Landing Gear Structure. For a typical 100 seats commercial aircraft application, we defined the following load conditions;

(1) Limit Load 200 kN for Tension
(2) Limit Load 330 kN for Compression
(3) Ultimate Load 300 kN for Tension
(4) Ultimate Load 500 kN for Compression

The Side Stay consists of the TiMMC tube and the monolithic titanium clevis ends, both ends of which were bonded by the diffusion bonding technology. This means that we were able to apply conventional design to the clevis ends and apply the law of mixture between the monolithic titanium and Silicon Carbide fibre for sizing the TiMMC tube section. The Interface is shown in Fig. 4 for reference.

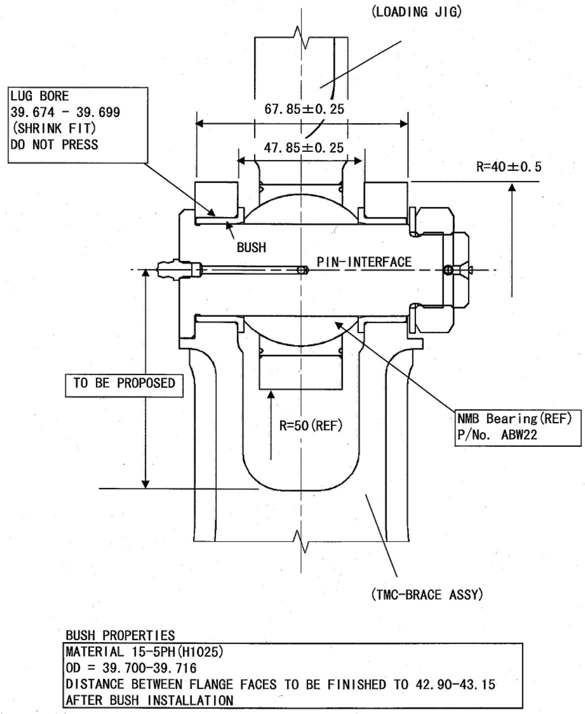

Fig. 4 Pin Interface for Side Stay

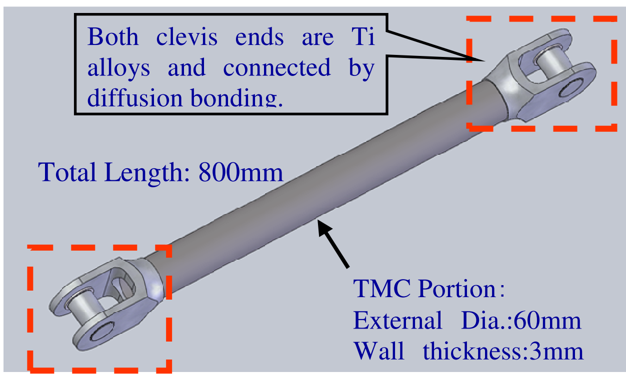

Fig. 5 Designed TiMMC Side Stay

The designed TiMMC Side Stay is shown in **Fig. 5 Designed TiMMC Side Stay**Fig. 5.

3.2 Prototype Manufacturing

We produced the prototype TiMMC Side Stay by using the HIP (Hot Isostatic Pressing) process to bond the Ti Clevis Ends to the TiMMC Tubular section and then applied conventional machining. The initial process is wrapping the uni-directional Silicon Carbide sheet and titanium foil to a mandrel. This wrap is then installed into the

HIP tool together with the monolithic Ti blocks, sealing, degassing and hipped as shown in Fig. 6.
After HIP, we decanned the component and machined the part to the finished dimensions.

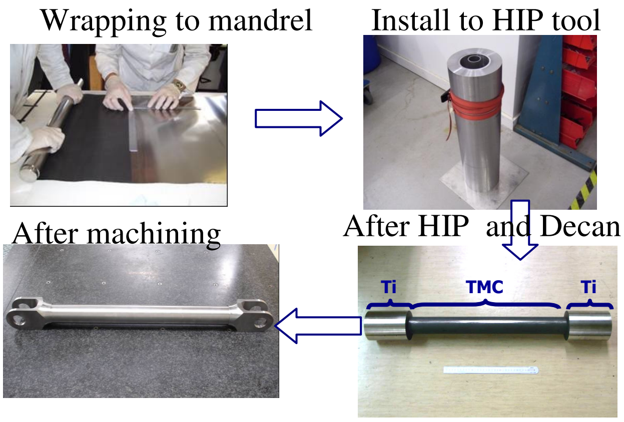

Fig. 6 Manufacturing TiMMC Side Stay

Prior to the final machining, we conducted FPI (Fluorescent penetrant inspection) and found no major inclusions. The final weight was 3.6 kg.

4 Test Results

4.1 Structural Testing of TiMMC Side Stay

To validate the structural integrity, we conducted a compression test as shown in Fig. 7. We measured the compression load and strain as shown in Fig. 8. The test results show good fit with buckling load by conventional calculation.

Fig. 7 Compression Test of TiMMC Side Stay

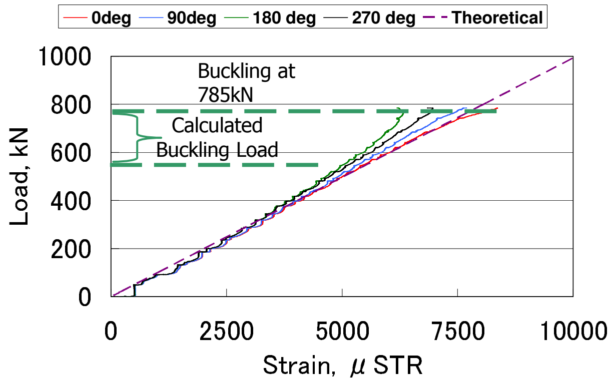

Fig. 8 Load Strain Data of Compression Test

4.2 Impact Test for Test Panel

To study the behavior of TiMMC's FOD (Foreign Object Damage) characteristic, we conducted the test by using TiMMC Test Panels and Instron Dynatup 9250HV Impart Tester as shown in Fig. 9.

Fig. 9 Instron Dynatup 9250HV Impact Tester

Impact energies of 20, 45 and 70 joules were applied. Typical results are shown in Fig.10 for 6-4Ti metals as our reference and Fig. 11 for TiMMC with or without 0.4 mm Titanium claddings for case of 45 joules, respectively.

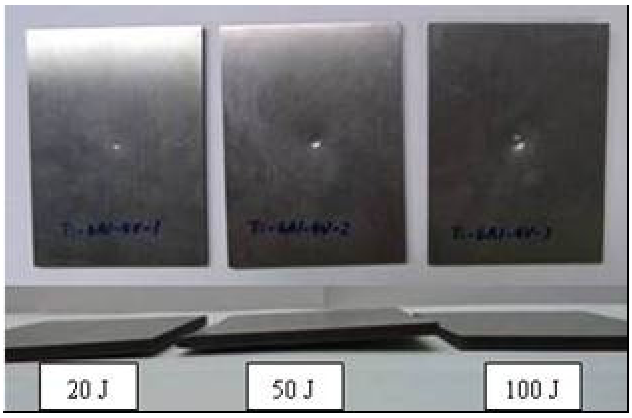

Fig. 10 Impact Test for 6-4 Titanium Test Pane

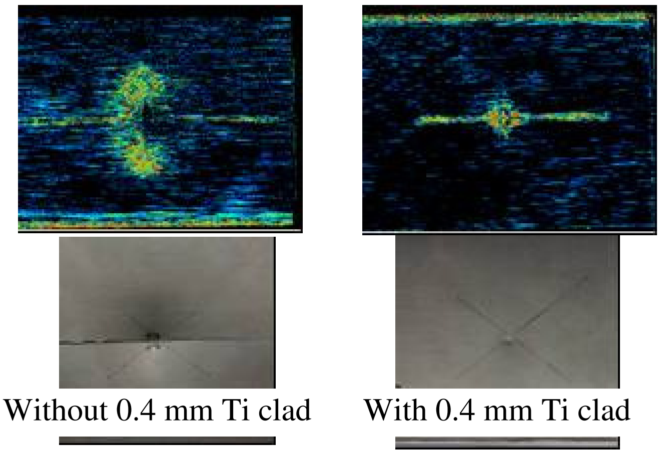

Fig. 11 45 joules Impact Test and its NDT results

Test results shows that the Titanium cladding alleviated the impact and shows some metal characteristics which indicates the impact stamp on the impact surface as shown in Fig. 11. Unlike CFRP composite, we could visually find impressions.

To validate this NDT results, we cut up the Test Panel and found some delamination and fibre failure as shown below.

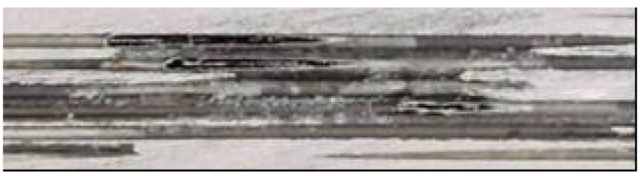

Fig. 12 Delimitation and fibre failure

4.3 Analytical Approach of Impact Test

Damage behavior of TiMMC subjected to FOD and resultant residual strength properties were studied by FEM-based numerical simulation.[4] As the damage due to static indentation is similar to that of low-velocity impact, quasi-static indentation simulation was carried out in order to predict damage behavior of TiMMC Test Panels with or without Titanium cladding. The calculation results are compared to test results for the 20 and 70 joules Test Panels.

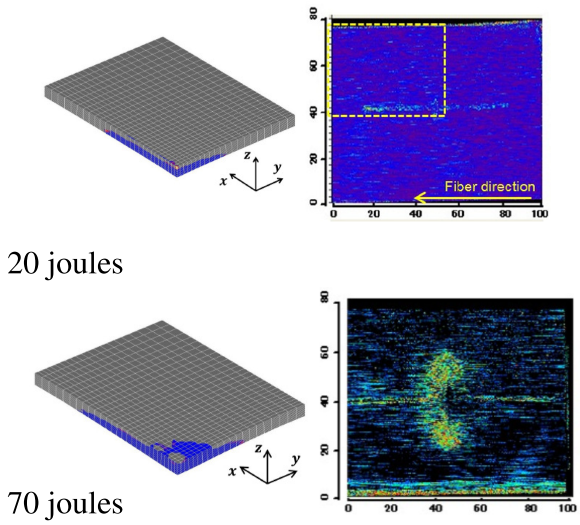

Fig. 13 FEM Analysis of Test Panel without Cladding.

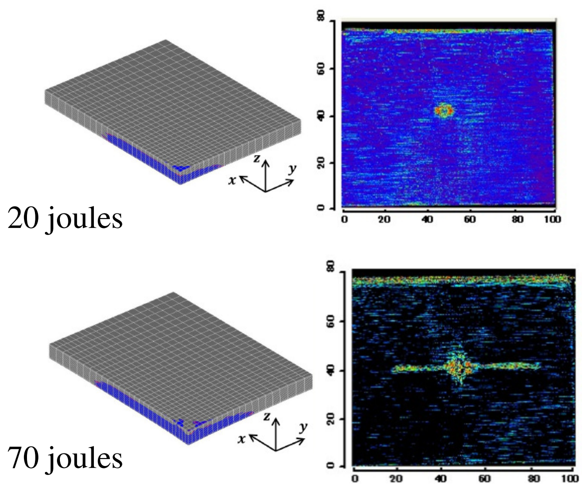

Fig. 14 FEM Analysis of Test Panel with Cladding.

Analytical results show larger damage compared to the test results. We found that the improvement of the failure law in our analytical approach should be considered.

4.4 Impact Test for TiMMC Side Stay

We conducted an Impact Test on the prototype Side Stay by using the same Impact Tester. To simulate the actual Landing Gear installation, we fixed the Side stay through the bearing joint as shown in Fig. 15 .

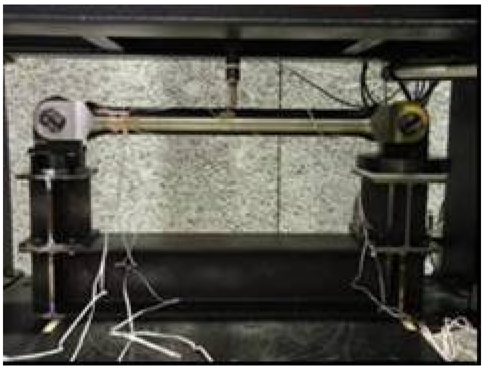

Fig. 15 Impact Test for TiMMC Side Stay

The impact energy of 40 joules was selected after considering the Test Panel Impact test as described in 4.2.

Fig. 16 Indication after 40 joules Impact Test

After Impact test, we found visual indication of the impact on the surface but no failure was found as shown in Fig. 16. We also conducted the NDT and found some indication as shown in Fig. 17.

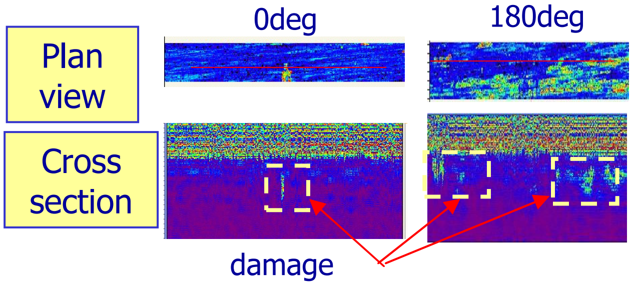

Fig. 17 NDT results after Impact Test

4.5 Compression After Impact Test

To check the structural integrity of the TiMMC Side Stay after Impact, we conducted the Compression test as shown in Para. 4.1. The test results are shown in Fig. 18.

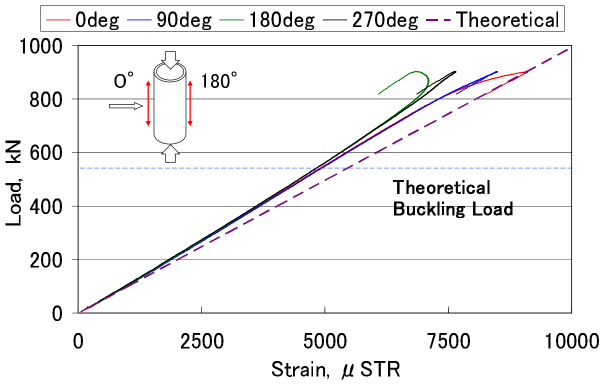

Fig. 18 CAI Test results for TiMMC Side Stay

No major structural degradation due to the 40 joules impact energy was found because the test results show good fit with the calculated buckling load. We concluded that the 40 joule impact energy is relatively small to fail the TiMMC structure.

4.6 NDI Approach after CAI

To confirm the damage effect of the 40 joule impact to the Side Stay, we conducted the NDT after CAI as shown in Fig. 19.

The major difference after CAI test is that some clear indication of failure was found. This is similar indication as shown in Para.

4.1. This means that there was Silicon Carbide fibre damage and also delamination occurred between the Silicon Carbide and Ti matrix.

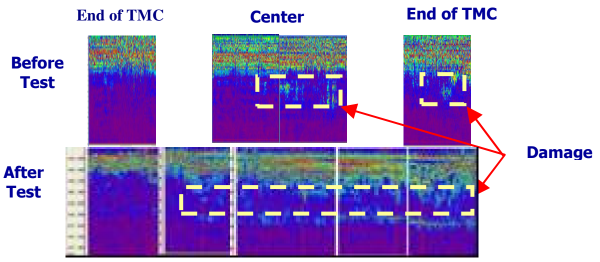

Fig. 19 NDT results before/after Compression Test

5 Cost and Weight Reduction Study

We compared the cost and weight of Side Stays against the conventional metal materials, and TiMMC as shown in Fig. 20 for a typical 150 seats class aircraft Landing Gear Side Stay.

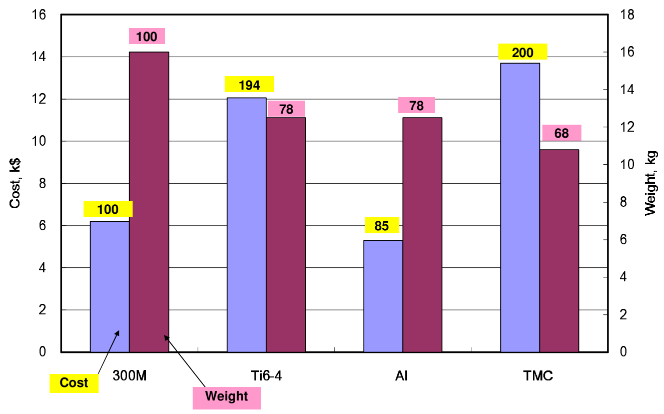

Fig. 20 Cost and Weight Study of TiMMC

We estimate to reduce the weight by 32% but increase two times production cost compared to the 300M material. In order to candidate the TiMMC as the future Commercial Aircraft Landing Gear Material, we have to introduce some challengeable productivity improvement to reduce the production cost

6 Conclusion

- To avoid the potential problems of 300M and at the same time reduce weight, two different types of New Composite Material were studied.
- CFRP is one of the potential candidates to apply to Landing Gear Components, but the current technology of the polymer matrix can achieve only aluminum alloy level strength for compression. In addition, the impact damage occurs in the depth of material. So, we expect that the polymer technology improvement is needed to increase the compression strength in order to apply CFRP to Landing Gear Components.
- TiMMC is also a potential candidate to apply to Landing Gear Components, and theoretically we can expect to reduce the weight. So, as the next step, we will further verify the material properties of TiMMC, such as the structural fatigue, larger Impact Energy, and Lightning Strike characteristics, prior to applying this material to Landing Gear Structural components.
- The use of composite materials to major components significantly reduces the weight of the landing gear versus traditional 300M. In addition, composites provide higher resistance to corrosion and fatigue than 300M parts, contributing to greater in-service reliability and greater time between overhauls.

7 References

[1] SAE AMS6257D, Steel Bars, Forgings, and Tubing 1.6Si - 0.82Cr - 1.8Ni - 0.40Mo - 0.08V (0.40 - 0.44C) Consumable Electrode Vacuum Remelted Normalized and Tempered, SAE International, 2007.

[2] SAE AIR5552, Development and Qualification of Composite Landing Gear, SAE International, 2010.

[3] Norman S. Currey, Aircraft Landing Gear Design: Principle and Practices, AIAA, 1988

[4] Keisuke Yoshida, Tomohiro Yokozeki, Kouta Fujiwara and Toyohiro Sato, Numerical Evaluation of Foreign Object Damage in SiC Fiber/Titanium Composite, Proceedings of 12th Japan International SAMPE Symposium, AER-2, 2011

Copyright Statement