Tensile Test Performance of Fibre Reinforced SMATed Aluminium Laminates

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Abstract. Fiber metal laminates (FMLs) are hybrid structures consisting of metal sheets and fiber reinforced plastic layers. Glass reinforced aluminum laminates (GLARE) reflects the combination of aluminum alloy layers and glass fiber reinforced layers. It is utilized in the aircraft upper fuselage and the leading edge surfaces of the vertical and horizontal tail planes at present. Surface mechanical attrition treatment (SMAT) is a technology which can improve the ultimate stress of metal. The SMATed aluminum alloy layers are introduced to the fabrication of new GLARE. After tensile test and theoretical calculation, the results show that the SMATed aluminum can improve the strength of GLARE obviously.

Introduction

With the progress of science and technology and fast development of the nanotechnology, there is more options for people to fabricate high strength and toughness metal. Many new techniques and methods have emerged, but the fabrication of evenly nano alloys is still a hard technical problems. surface mechanical attrition treatment (SMAT) is a advanced technology of nanometerization which can increases strength of metal [1-5]. A typical of schematic of the SMAT technique is shown in Fig. 1. The ceramic spheres are filled in a cylinder-shaped chamber connected to a vibration generator. With the high frequency vibration, sample surface to be treatedis hit repetitively in random direction by a large amount of balls within a short period of time, resulting in a severely plastically deformed sample surface layer. The basic principle of the SMAT treatment is the generation of severe plastic deformation in the top surface layer of a bulk material by means of repeated multidirectional impacts of flying balls on the sample surface [6].

Grain size refinement in metals, achieved via cold working for some alloys, is widely accepted as a way to improve many of their mechanical properties. Specifically, a material's strength is known to increase linearly with the inverse square root of the grain size as given by the Hall–Petch model [7, 8]:

$$\sigma_y = \sigma_0 + kd^{-\frac{1}{2}} \tag{1}$$

where k is a positive multiplicative constant and is the lattice friction stress.

GLARE is a hybrid material of glass reinforced laminate and aluminum alloy layers. It have the advantages of glass reinforced laminate and aluminum. are designed to be a good damage-tolerant material (incl. slow crack propagation) due to fatigue in aerospace structures. For example, high fatigue resistance is achieved by fiber bridging of fatigue cracks. If a crack has initiated in the aluminum alloy layers, some limited delamination will occur at the interfaces between the metal and

the fibers. That will accommodate stress re-distribution from the metal to unbroken fibres in the wake of crack. Crack bridging provided by the strong fiber restrains crack opening, and thus reduces the driving force for crack growth in the metal layers [9-11].

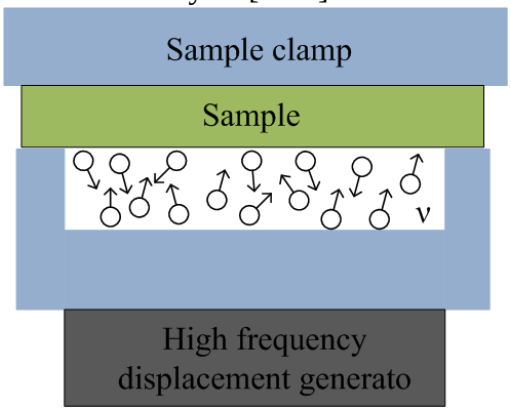

Fig. 1 Schematic illustration of the SMAT technique

Many studies about the influence of SMAT to steel have been done by Lu [12-14]. Shot blasting and SMAT have been introduced to the treatment 2024 and 7075 aluminum by Cho and Wu, respectively. In this paper, The SMATed aluminum alloy layers are introduced to the fabrication of new GLARE. And the tensile test performance will be studied.

Experiment

Materials

The alloy 2024 plate products are most used in fuselage structural, wing tension members, shear webs and ribs and structural areas where stiffness, fatigue performance and good strength are required. It is noted for its excellent toughness at moderately high strength levels. With its relatively good fatigue resistance, Alloy 2024 continues to be specified for many aerospace structural applications. Chemical compositions of Al-2024 is listed in Table 1.

Tab. 1 Other composition of 2024-T3 (Weight%)

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
6061-T6	0.4-0.8	≤0.7	0.15-0.4	≤0.15	0.8-1.2	0.04-0.35	≤0.25	≤0.15
2024-T3	0.5	0.5	3.8-4.9	0.3-0.9	1.2-1.8	0.10	0.25	0.15

SMAT and the fabrication of GLARE

In the SMAT treatment, small ceramic ball impact the metal surface from different direction. And the detail of this process is shown in Table 2. The alkali wash, deoxidize and anodizing which is shown in Table 3 is essential to Al-2024 of GLARE. The fabrication GLARE is hot press. The configuration of GLARE and the tensile test sample is shown in Fig. 2 and Fig. 3, respectively. The tensile test of the GLARE is operated on MTS tensile test machine, the largest loading is 50 kN.

Tab. 2Treatment parameters in SMAT process

Diameter of the ball (mm)	Amount of the ball	Treatment time (min)	Amplitude(%)
2	600	1	30

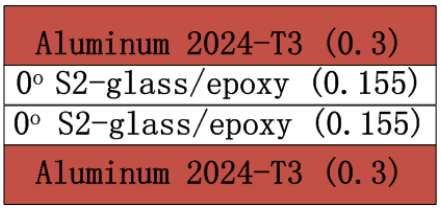

Fig. 2 A schematic of the GLARE 2 specimens with (2/1) configuration

Tab. 3 Step of anodizing treatment on Aluminium alloy

Step	Composition	Technology
1 Clean	Acetone	Wipe
2 Alkali wash	NaOH，25-30g/L，Na_2CO_3，25-30g/L	50-60°C，0.5-1min
3 Rinse	Clean water	2-5min
4 Deoxidize	HNO_3，300-500g/L	Room Temp，2-5min
5 Rinse	Clean water	2-5min
6 Anodizing	H_3PO_4，120-140g/L	Temp，25±5°C，DC，10±1V，Time，20±1min
7 Rinse	Water	5min
8 Wet	——	60°C 15min

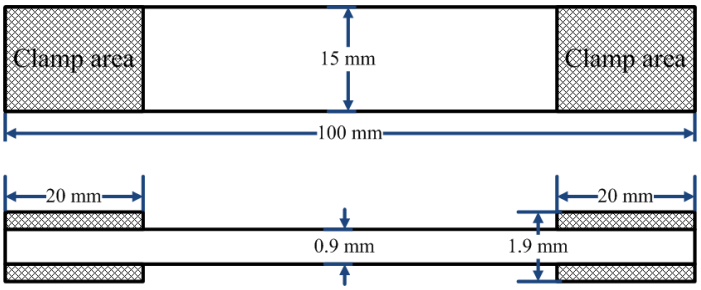

Fig. 3 Illustration of experimental set-up for tensile test

Results and discussion

The metal volume fraction (MVF) is proposed for the tensile test performance of fiber metal laminate by M.S.pma [15]:

$$MVF = \frac{\sum_{1}^{p} t_{al}}{t_{lam}} \tag{2}$$

Where t_{al} is the thickness of single aluminum; t_{lam} is total thickness of the GLARE; P is the number of layers.

The main mechanical property of GLARE can be given.

$$E_{lam} = MVF * E_{met} + (1 - MVF) * E_{FRP} \tag{3}$$

$$\sigma_{y,lam} = [MVF + (1 - MVF)\frac{E_{FRP}}{E_{met}}] * \sigma_{y,met} \tag{4}$$

$$\sigma_{ult,lam} = MVF * \sigma_{ult,met} + (1 - MVF) * \sigma_{ult,FRP} \tag{5}$$

Where E_{FRP} and E_{met} the elasticity modulus of glass fiber reinforce laminate and aluminum. And, $\sigma_{y,met}$, and $\sigma_{ult,met}$, are the yield strength of aluminum. $\sigma_{ult,FRP}$ is the strength of the glass fiber reinforce laminate.

The volume fraction of GLARE can be got easily from the information of Fig. 2. Then, the tensile test property of specimens Al-2024-T3 with/without SMAT and epoxy glass fiber composites, which is shown in Table 4, is put into the formula (3), (4) and (5). So, the theoretical tensile properties of GLARE is shown in Table 5. After comparing of yield stress and ultimate stress between theoretical and experimental results which is shown in Table 6, the results is very close. Besides, the SMATed GLARE have lower yield strength, however , it have higher ultimate strength.

Tab. 4 Tensile test property of specimens Al-2024-T3 with/without SMAT and epoxy glass fiber composites

Specimen	Ultimate stress (MPa)	Ultimate strain (%)	Young modulus (GPa)	Yield stress (MPa)
No SMATed 2024-T3	230.6	18.5	56.4	113.4
SMATed 2024-T3 with1 min	224.3	16.5	59.1	151.0
Epoxy glass fiber composites (0^o)	1900	——	54	——

Tab. 5 Theoretical tensile properties of GLARE

Specimen	Ultimate stress (MPa)	Young modulus (GPa)	Yield stress (MPa)
GLARE without SMATed 2024-T3 aluminium	798.2	55.6	111.8
GLARE with SMATed 2024-T3 aluminium	794.0	57.4	146.6

Tab. 6 Comparison of Yield stress and ultimate stress between theoretical and experimental results

GLARE	Ultimate stress (MPa)			Yield stress (MPa)		
	Theoretical result (MPa)	Experimental result (MPa)	Percentage of error	Theoretical result (MPa)	Experimental result (MPa)	Percentage of error
Without SMATed	798.2	720	10.9%	111.8	101	10.7%
SMATed	794.0	673	18%	146.6	124.5	17.8%
Percentage of increase or decrease	↓ 0.5%	↓ 6.5%		↑ 31.1	↑ 23.3	

Summary

The GLARE is fabricated through hot-press process and consist of SMATed aluminium and glass fibre epoxy prepreg. After tensile test and theoretical calculation, the results show that the SMATed aluminium can improve the strength of GLARE obviously. This means that it could achieve the best effectiveness of use in some special occasion.

Acknowledgement

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