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Study on impact damage mechanisms and TAI capacity for the composite scarf repair of the primary load-bearing level

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ABSTRACT

As composite material plays a leading role in aircraft, composite bonding repair has been extensively applied. Among composite bonding repairs, the scarf bonding repair is widely adopted and has high repair efficiency especially in primary load-bearing structures. However, the impact damage tolerance and impact damage mechanisms were not considered for repaired structure integrity design yet. This paper experimentally and numerically studied the scarfed bonding repair of the advanced CFRP, which may suffer a low velocity impact load in service. At the central location of adhesive zone, impact energy and response regularity were studied to reveal the competition failure mechanism for inner kinds of materials. In the impact procedure, double force peaks phenomenon and four typical phases were found. Tension after impact (TAI) capacities were also tested to explain the impact damage effects on residual strength. The adhesive damage has strong influence over tension after impact capability. The most easily broken location in the bonded zone is the feathered tip on the back of impact point. The critical impact energy 23 J exists for this size of specimen. When the impact energy is higher than the critical 23 J, except for the composites damage, the adhesive damage can be observed at the second force dropping. The scarfed adhesive damage occurred at the scarf feathered tip of back side.

1. Introduction

Advanced CFRP (Carbon Fiber Reinforced Plastics) application in aircraft has turned from secondary structures to primary load bearing structures. High strength and middle modulus CFRP promote composites application to load bearing structures, such as T700, T800, T1100 and MJ series. Damage of aircraft load bearing level structures always occurred in impacting and maintaining. As composites have low interlaminar toughness, low velocity impact leads to an invisible inner damage. For the upgraded composites, the mechanical characteristics would change. Hence, the problems of composite repair exist in load bearing structures and are complicated and important [1,2].

At present, composite repair technique has become one of key factors for further composite applications. The existing aircraft structures design considered only the static strength, stiffness recovering level, but didn't include the second impact in the service of repaired structures. When stepped and scarf repaired structures are impacted, the innerlaminar, interlaminar and adhesive will suffer damage in some extent. The competed failure mechanisms of different materials must be revealed clearly to obtain the impact tolerance and resistance for composite repairs.

Low velocity impact has strong influence to composite stepped and scarf repairs [3–5]. In 2006, U.K. Vaidya [6] found that out-plane load leads to higher peel stress and concentration than in-plane load case, and adhesive crack initiates as mixture mode and transforms to mode II. In 2007, I. Takahashi [7] applied health monitoring technique to detect scarf adhesive damage. A.B. Harman [8] discovered that the impact damage tolerance for composite scarf repair structure reduced comparing with laminate plates. H.C.H. Li adopted quasi-static out-plane load to substitute impact dynamic load and found that in-plane prestrain affects bending stiffness. In 2012, M.K. Kim [9] studied the impact damage of laminate plates and composite scarf repair under combined in-plane load and out-plane impact, and gave the conclusion of that impact resistance increase obviously as the prestrain increases. Berrin Gunaydın [10] investigated the effects of composite repair patches and number of patch layers on the fatigue behavior of surface-notched composite pipes. In 2015, C.H. Wang [11] experimentally studied CAI (Compression after Impact) mechanical performance for 2 mm thickness stepped repair. C.H. Wang [12] proposed that the existed design methodologies consider only loading capacity of integrated repair structures without including adhesive damage

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and delamination. J.J. Andrew [13] conducted experiments of multiple low velocity impact and CAI for GFRP bonding lap joints. Effects of number of patch layers on the burst pressure of low velocity impact damaged tubes that have been repaired with composite patches were investigated [14]. In 2016, G. Balaganesan [15] found that the patch of GFRP stepped repair structures could absorb 50% to 80% impact energy. In 2017, O. Balcı [16] studied the honey comb GFRP structures repaired by lap joint and concluded 3 J impact energy produce surface damage and 8 J is the critical penetrated energy. S.R.M. Coelho [17] concerned the mechanical performance and the damage for single patch and double patches with multiple impacts. In summary, impact problems of composite scarfed and stepped repair were studied by few researchers, but impact response, damage mechanisms and damage modes were not researched systematically. The conjunction studies of macroscopic damage phenomenon and microscopic failure cracks [18–20] were conducted much less and needed to be carried out.

2. Specimens and tests setup

2.1. Specimens

As shown in Fig. 1, the specimen length, width and thickness are 300 mm, 50 mm and 4 mm [5]. Scarfed surfaces with the angle of 5° were cut and polished by machines. The scarf bond length is 45.7 mm and the bond surface thickness is 0.2 mm. The supplements of both ends are clamped area for tensile test machine and the size is 50 × 50 mm. To avoid the stress concentration, the clamped supplements were machined with the angle of 15°.

The composite scarf adherends are hard patch repair which were pre-cured. The composite adherends were fabricated using the layup consisting of 32 plies of high performance T700/LT03A carbon/epoxy prepregs. The stack sequence of composites is [45/0/-45/90/0/45/0/-45/0/0/90/0/-45/0/45/0]$_S$. The percentage of 0°, 45° and 90° is [50/37.5/12.5]%. This kind of layup being composed of 0° of 50% is a representative for primary-load bearing composite structures [1]. The prepreg material has a nominal ply with thickness of 0.125 mm and curing temperature of 120 °C.

The adhesive used to joint two composite adherends which were made from epoxy of Cytec FM73M with thickness of approximately 0.2 mm and curing temperature of 120 °C. FM73M is an aerospace high-performance film adhesive.

2.2. Tests setup

On account of that the existing impact standards for composites didn't include relative narrow specimen, we designed the narrow impact setup for composite scarf repair by referring to A.B. Harman and A.N. Rider [5]. Fig. 2(a) shows the schematic of impact fixture and specimen. Fig. 2(b) shows the experimental setup coinciding to Fig. 2(a). The drop-testing machine Instron-9250HV was used and the tip diameter was 16 mm. The quality of the punch is 5.067 kg. During impact process, the responses of impact load, deflection, velocity, absorbed energy and time can be obtained by the testing machine. To investigate the effect of impact energy on composite

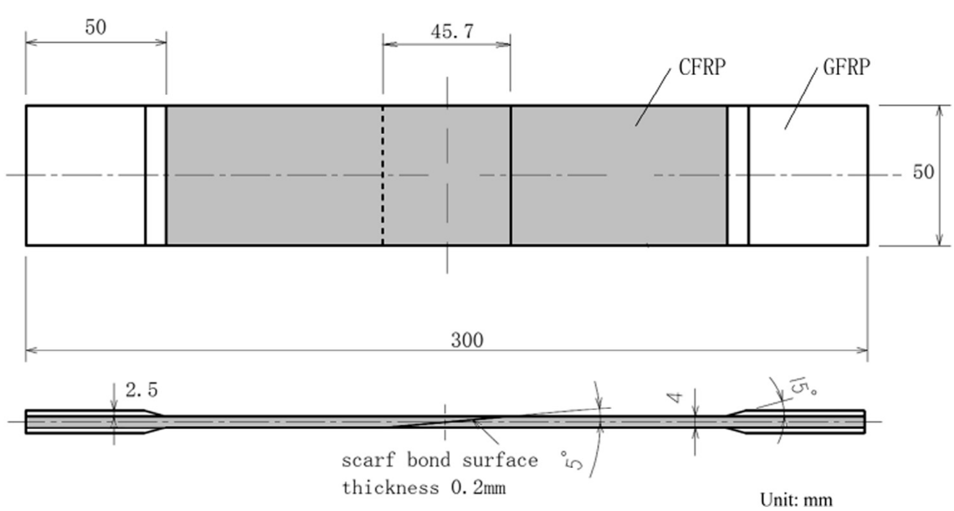

Fig. 1. Specimen schematic of the composite scarf repair.

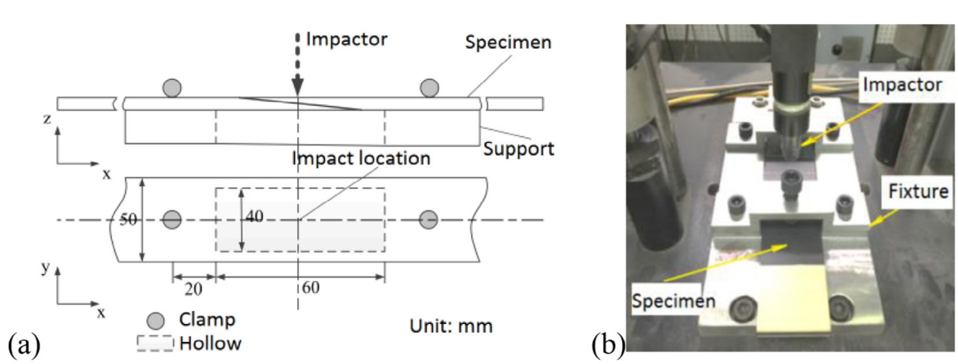

Fig. 2. The impact fixture and specimen: (a) schematic; (b) setup.