OPTIMIZATION OF HYBRID COMPOSITE-METAL JOINTS

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Abstract: Better understanding of the methods of composite and metal joints in airline industry has a significant role in reducing the operational costs. New joining methods between composites and metals are investigated involving additive manufactured rivet pins. This paper focuses on numerical analyses of the strength of the joint, as well as optimization of the pins. The joint morphologies of metal to metal, metal to composite materials were studied through the finite element analysis, involving individual and multiple pins and adhesive-bonding layer joint models.The results show that the largest shear stress in the pin occurs at the cross section between the bottom of the pin and the metal plate. In addition, bearing stress around the composite hole for the pin increases with the external tensile loading. Besides, a plot of the shear stress along the loading direction can be obtained by modeling six pins. The conclusion is that by optimizing the shape of the pins, the shear stress and axial stress are reduced.

Keywords: Optimization, Hybrid joints, Finite element analysis, Pin, Stress

1.INTRODUCTION

In recent aircraft generations, manufacturers have shifted the main structural material from aluminium alloys to composites. For instance, Airbus A350 and Boeing 787 have more than 50% of their structure from composites(Figure 1)[1-5]. Composites have many advantages over conventional aluminium alloys, which made aviation industry to propel their production. Composites have very high specific strength to weight ratio compared to aluminium alloys, but when they are riveted, more than 60% of the material strength is lost due to the presence of the holes. Holes made in the composite structure for riveting introduce damage to the plies and this may cause composite material to fail without any early detection before the scheduled maintenance checks[6-9]. Riveting process of composite parts is still common practice in airline industry maintenance as a quick and temporary solution. Metallic (aluminium alloys and titanium) and composite materials (especially carbon-fibre-reinforced-polymers (CFRPs)) can be used in joints to meet the requirements, which are lightweight and high specific strength. With the increasing application of composite materials in airline industry, better understanding the methods of composite and metal joints has a significant role in enhancing safety and reducing costs[7-12].

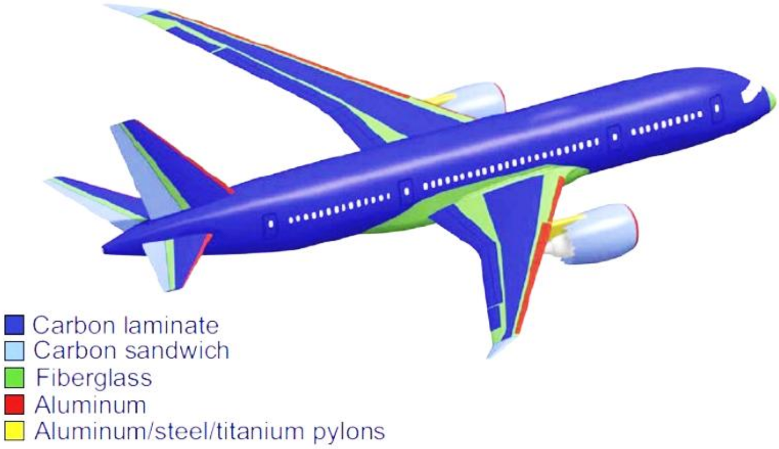

Figure 1. The ratio of materials used in Boeing 787

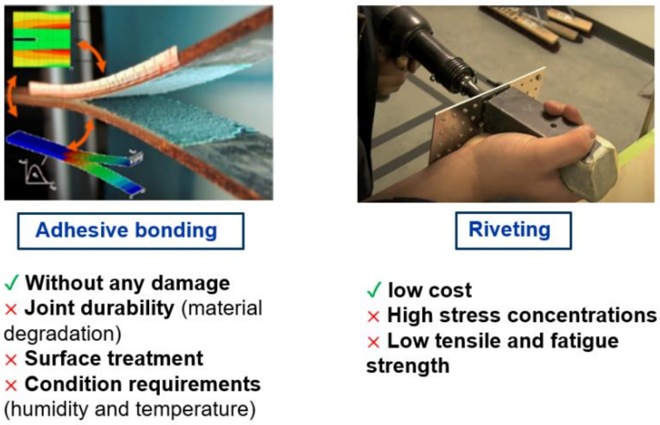

Figure 2. Compare with adhesive bonding and riveting

As for metal to composite joining, the most commonly adopted techniques at present are mechanical fastens and adhesive bonding. As it shows in figure 2, both of the adhesive bonding and riveting have advantages and disadvantages[13-14]. The advantage of adhesive bonding is that it can make the joining of two material plates without any damage, which is the disadvantage of riveting because of damaging the internal structure. However, the limitations are joint durability (material degradation), surface treatment and condition requirement (humidity and temperature). For example, airplanes encounter cold weather and humidity when flying at high altitude and the adhesive bonding will lose its effectiveness. While for riveting, the cost of manufacturing is low. But it has high stress concentrations at holes and low tensile and fatigue strength[15-16].

In order to solve this problem, we need to study some different methods of joining between composite and metal mentioned in the previous research literature, such as friction spot joining(Figure 3). It has high strength as well as lightweight and low cost[17]. In addition, the advantage of selective laser melting is without the need for surface preparation[18]. What's more, induction spot welding and hybrid penetrative reinforcement(Figure 4) also have a rapid heating and higher strength[19-20]. By comparing the previous connection methods of metal and composite, the joining method proposed in this research is to combine the riveting and adhesive bonding together.

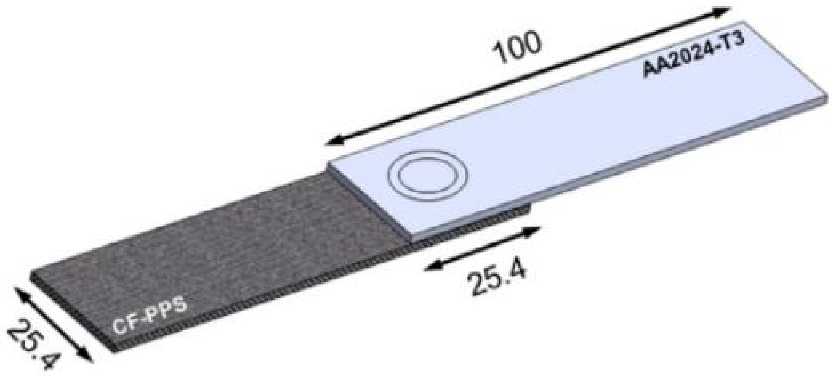

Figure 3. Configuration and dimensions of the friction spot joints(in mm)[17]

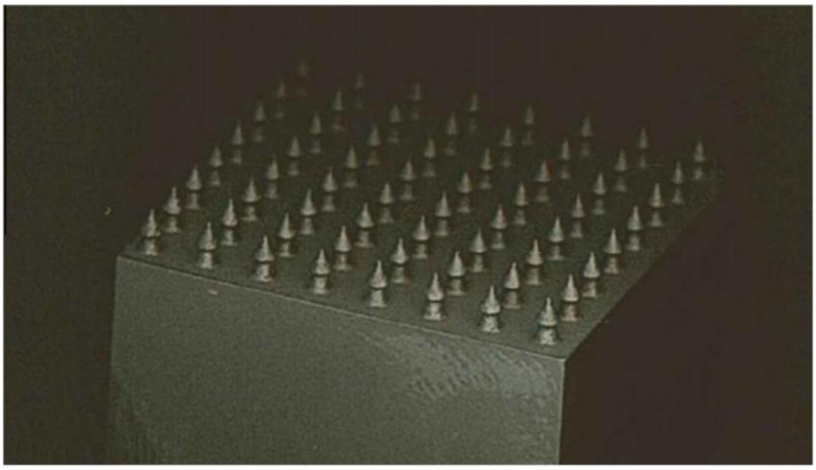

Figure 4. An array of additively manufactured, titanium HYPER pins[20]

2.METHODOLOGY

The methods of this research are numerical analysis and experimental test.

2.1 Numerical analysis

At the moment, finite element analysis (FEA) was used of metal to composite joints involving single and multi-pin matrix model with adhesive bonding. The model divides into three parts, top metal plate with a pin growing on the bottom surface, middle adhesive layer and the bottom composite plate(Figure 5). Abaqus was used to build the model with one pin and adhesive bonding layer to analyse the stress. After that, metal plate, composite plate, adhesive layer and pin were defined in the form of some partitions with different material properties(Table 1-2). The first layer of the composite plate was set at an angle of zero degrees along the X-axis, the second one at 45 degrees, and the third one at 90 degrees. Then the model was meshed with different mesh type, such as structure and sweep. The refined mesh was made near the pin and a coarser mesh was made far-away from the pin features(Figure 6). By setting certain boundary conditions and loads, Von Mises stress and shear stress were calculated to analyse the place where the maximum stress appears.

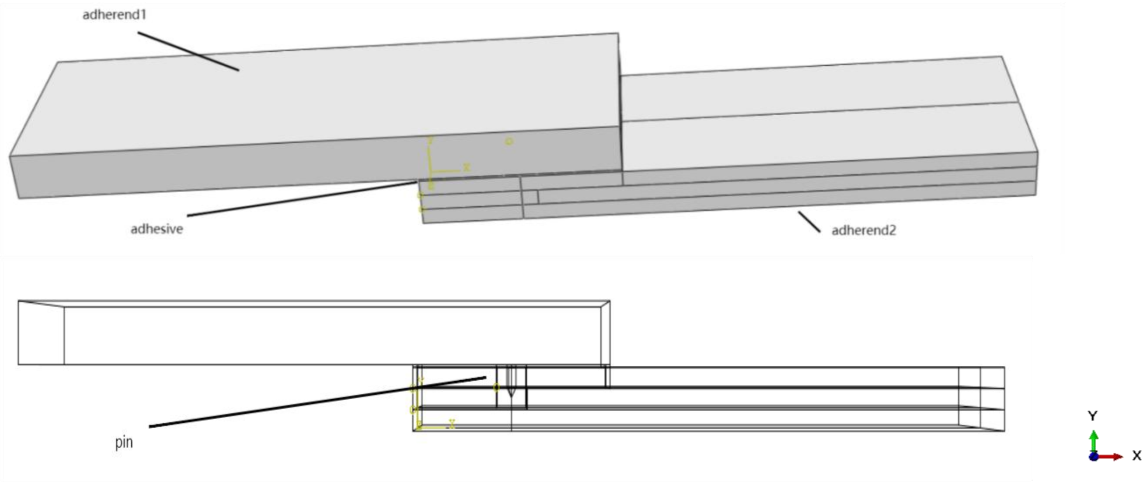

Figure 5. model of metal (adherend 1) and composite (adherend 2) joint

Table1. Material Properties

Section	*Young's Modulus,E (MPa)*	*Shear Modulus, G (MPa)*	*Poisson's Ratio*
Adherend 1, pin	116000	44000	0.3
Adhesive	2800	1100	0.3

Section	E_{xx} *(MPa)*	E_{yy} *(MPa)*	E_{zz} *(MPa)*	G_{xy} *(MPa)*	G_{xz} *(MPa)*	G_{yz} *(MPa)*	v_{xy}	v_{xz}	v_{yz}
Adherend 2	157000	8500	8500	4200	4200	4200	0.35	0.35	0.35

Table 2. Geometry

Parameters	*Value (mm)*
Pin base diameter	2.00
Pin height	3.00
Adherend 1 thickness	5.00
Adherend 2 thickness	5.00
Adhesive thickness	0.25
Adherend length	75.00
Overlap length	25.00

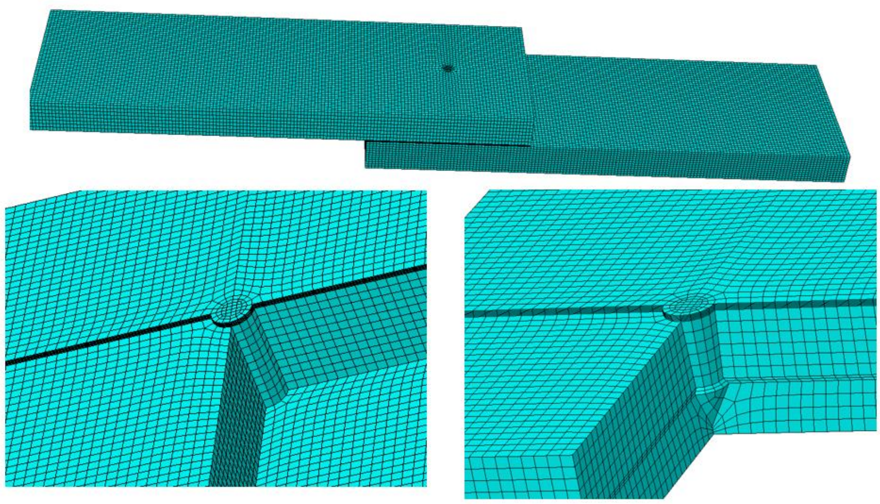

Figure 6. Mesh of model with 1 straight and shape pin

2.2 Experimental study(future work)

Next step the experimental study will be conducted. The method of making the pins is 3D printing, which will be used to make the structures and mechanical testing by advanced condition monitoring technologies. First, I will make a single pin growing on the surface of metal plate. Then, the pin with adhesive layer will be pushed into the composite plate. In addition, multi-pins will be made to compare with the single pin and to find the best way of joining. Focus will be on the failure mechanisms of such joints under various design and loading scenarios.

3.NUMERICAL SIMULATION RESULTS

At the moment, the stress of the model and the stress distribution inside the connection were studied. In addition, the early results were obtained from the model I made with 1 pin and adhesive layer. By setting boundary conditions (fixed the left side of the metal plate) and loads (along the X direction on the right side of the composite plate), results show that the largest shear and tensile stress of the pin occur at the cross section between the bottom of the pin and the metal plate(Figure 7). The bearing stress around the composite hole increases with the tensile loading. In addition, the distribution of stress changes over the range of the parameters we considered. Besides, a plot of the shear stress along the loading direction can be obtained by modelling six pins distributed along the centre line of the adhesive layer(Figure 8). Two sides of the pins have the large shear stress. Stress magnitude and concentration can be reduced by optimizing the number and shape of the pins. A sensitivity study of the different parameters(Table 3) is carried out for finding an optimized pin by combining shear and tensile stress(Figure 9).

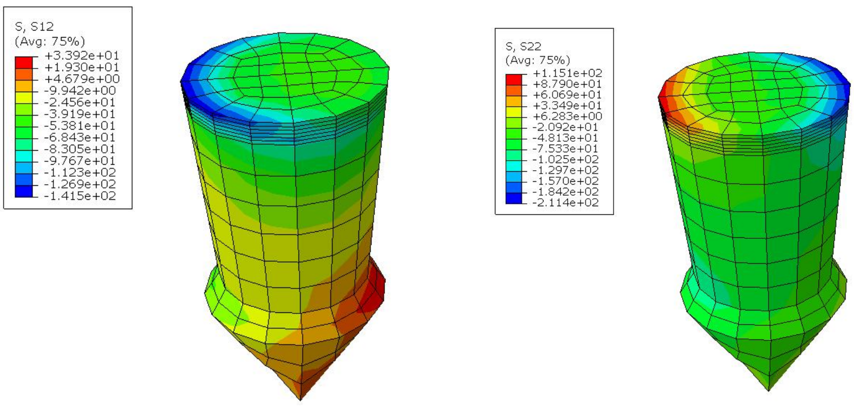

Figure 7. Shear stress(S12) and Tensile stress(S22) of 1 pin

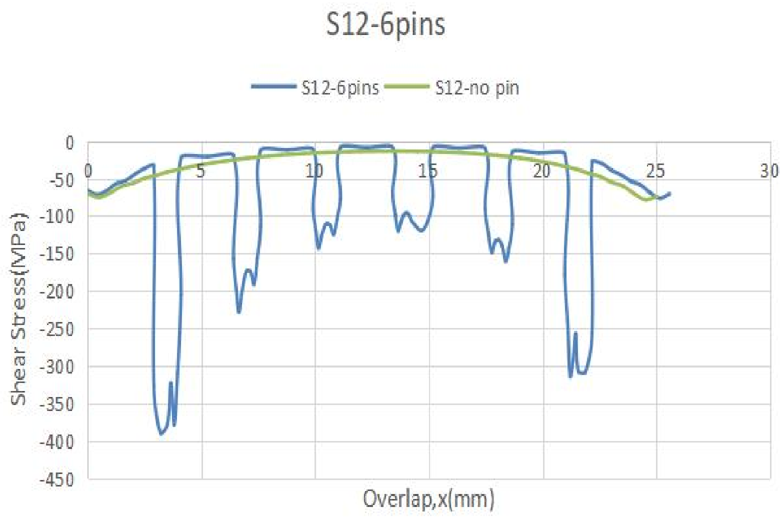

Figure 8. Shear stress of six pins distribution along loading direction

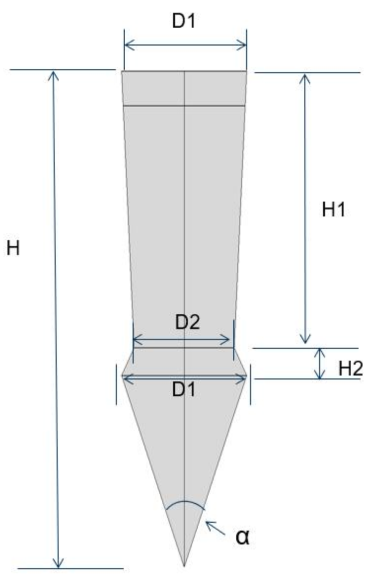

Figure 9. Parameters of 1 pin

Table 3. Parameters of 1 shape pin

Parameters	*Constraint (°，mm)*
α	60-180
D1	2-3
D2	1-2
H1	1-3
H2	0.1-0.3
H	<=5

Table 4. Sensitivity study of 1 shape pin

*Sensitivity study(%), (S_{max}-S_{min})/S_{max}*100%*					
Section	*D1*	*D2*	*H1*	*H2*	*H*
$S_{12,shear}$	4.33	4.86	5.70	4.75	11.93
$S_{22,Tensile}$	2.13	2.90	2.46	2.20	3.07
$S_{22,Compressive}$	22.93	9.89	18.04	13.54	18.05

Although compressive stress has a great effect, we do not consider the effect of compressive stress in the actual experiment. Shear stress and tensile stress have greater damage to the specimen. Also, the total height of pin has great influence on the shear stress(S12) in pin and S12 decreases with the increase of the height. However, it has little effect on axial stress(S22) in both pin and adhesive(Table 4). For axial stress(S22), the shape of pin (especially the angle) has a greater effect on it. Besides, by optimizing the shape of pin(Table 5), the shear stress and axial stress are reduced(Figure 10).

Table 5. Optimization of 1 pin(minimum stress of S12 and S22)

Section	*Angle(°)*	*D1(mm)*	*D2(mm)*	*H1(mm)*	*H2(mm)*	*H(mm)*
Best pin	60	2.00	1.60	1.50	0.20	3.43

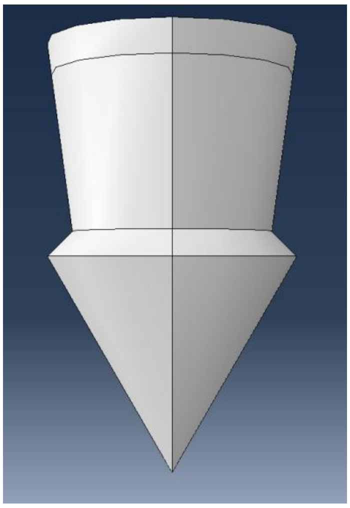

Figure 10. Optimization of 1 pin

4.FUTURE WORK

A parametric study will be carried out for joint design optimization involving aluminum and titanium alloys and carbon fibre reinforced composites with multi-pins in rows and matrix. Finite element analysis will continue to be done.

At the same time, experimental study using additively manufactured pins will also be conducted. The model of laser processing machine is LiM-X260A and the manufacturer is Tian Jing Lei Ming, China. Some of the parameters of the machine is shown in Table 6 below.

Table 6. Parameters of the machine

Parameters	*Value*
Power of IPG, (W)	500
Laser spot diameter, (mm)	0.07-0.12
Scanning speed, (m/s)	≥7
Maximum molding size, (mm)	260*260*400

3D printing will be used for making pins growing on the surface of metal plate and mechanical testing by advanced condition monitoring technologies. Through the optimization of the finite element analysis results, pins of different sizes will be made, then how they are inserted into the composite plate will be considered. At the same time, the strength test will be carried out. After that, multiple pins will be made on the metal plate to compare with single pin. This research will put forward optimization of joining configurations between composites and metals for improved strengths.

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