Investigation on the effect of drilling parameters on tensile loading of fibre-metal laminates

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Abstract. This study conducted to investigate the effect of different drilling parameters on the strength of vacuum infusion fibre reinforced epoxy resin-based fibre metal laminates (FML). The effect of several parameters such as the speed of drilling (1050, 2020, and 2750 rpm) and feed rate of (0.05, 0.1, and 0.15 mm/rev), and the thickness of FML on the strength of the composite materials were studied experimentally. The FML has been analysed under static loading. Drilling at lower spindle speed and lower feed rate results in better strength than higher spindle speed and feed rate. Then, the thicker FML gives more strength compare to the one with less thickness.

1. Introduction

Fibre Metal Laminates (FML) is an outstanding composite materials that have been used widely in aerospace owing to their excellent strength to weight ratio performance, low density and excellent corrosion resistance. However, the application FML in marine industry such as for small boat is still new and need a lot of research. Drilling is the most common machining process applied for joining these materials which not only reduces the structural integrity of the materials, but as well has the potential for a long-term performance deterioration [1] [2].

Various studies have been carried out on the effect of drilling process on FML, but most of the studies only focusing on the effect during the drilling process. Not many research purposing on the tensile behaviour of drilled specimen. Kılıçkap et al. [3] has studied on the effect of delamination factor on strength of glass fibre reinforced plastic (GFRP). The experiment was conducted at different drilling parameter such as cutting speeds and feed rate using tungsten carbide (WC) and Brad Spur cutting tools. It was determined that when the cutting speed and feed rate are increased, the delamination factor also increased which then lead to the reduction in strength of GFRP composites.

In addition, Pandit and Prasat [4] have studied on effect of drilling parameters on residual tensile strength of specimen and surface roughness of drilled hole using Taguchi method of optimization. The drilling parameters used were cutting speed, feed rate, drill point angle (DPA) and chisel edge width (CEW) for drilling of CFRP composites. As results, speed was the major factor contribute to changing in residual tensile strength followed by chisel edge width, drill point angle and feed rate. For surface roughness, drill point angle gave major contribution followed by speed, feed and chisel edge width.
Kumar et al. [5] have studied on the effect of thickness on tensile properties of a hybrid composite. The specimens of GFRP have been prepared at different thickness of 2mm and 3mm. It indicated that tensile strength mainly dependent on thickness of laminated polymer composites. If thickness increased by 1 mm, then 40-50% more load was required for fracture. So, increase in thickness of laminates resulted in increase of tensile strength.

In this present study, the effect of drilling and specimen parameter of FML, at different cutting conditions, was conducted. The drilling condition parameters were characterized by spindle speed and feed rate while the specimen parameter was categorized by the thickness of the specimen. After characterizing, specimens have been tested under stress load to investigate the tensile behaviour towards specimens.

2. Experimental materials and methods

2.1. Materials

FML is made up from hybrid combination of aluminium sheet and woven roving glass fibre. Aluminium sheet of 0.6 mm thickness and woven roving glass fibre of 450 gsm density were used in this research. Epoxy Epicote 2715 were used as a matrix and adhesive bonding. The fabrication process for the FML was vacuum infusion process which is one-time process, laminated the woven roving glass/epoxy at the same time bonded the laminate to the aluminium. FML 3/2 sample divided into two group which is 3A2F and 3A4F. 3A represented 3 layers of aluminium and (2F, 4F) represented 2 layers of woven roving glass/epoxy. As shown in Table 1, the thickness of woven roving glass/epoxy was maintained at ±0.37 mm regardless the number of fibre layers used. The sample were cut according to ASTM D3039 standard dimension for tensile test. Precise positioning and controlled FML movement during the cutting process must be taken to ensure a defect free delamination. Schematic drawing of FML illustrated in Figure 1.

| Sample Designation | FML Thickness (mm) | Aluminium Thickness (0.6 X 3) (mm) | No. of Fibre Layer | Thickness of Single Fibre Layer (mm) |
|--------------------|--------------------|----------------------------------|-------------------|-------------------------------------|
| 3A2F               | 3.28               | 1.8                              | 4                 | 0.37                                |
| 3A4F               | 4.78               | 1.8                              | 8                 | 0.37                                |

Table 1. Details of FML specimens.

![Figure 1. Schematic drawing of FML.](image)

2.2. Drilling process

Universal Milling Machine DECKEL MAHO DMU 50, with the spindle rotational speeds (range from 20 to 18,000 rpm) and feeding rates maximum of 600 mm/min was used for drilling the specimens in this study. High Speed Steel (HSS) drill bit of 8 mm diameter was used during drilling process. The specimens were drilled under dry cutting conditions comprising of three spindle speeds (N= 1050,
2020, and 2750 rpm), and three feed rates ($f = 0.05, 0.1$, and $0.15 \text{ mm/rev}$) at the centre of specimen as shown in Figure 2. The levels defined for each of the process parameters are summarized in Table 2.

### Table 2: Drilling parameters and their levels [6].

| Drilling Parameter       | Levels       |
|--------------------------|--------------|
|                          | 1            | 2            | 3            |
| Spindle Speed ($N$, rpm) | 1050         | 2020         | 2750         |
| Feed Rate ($f$, mm/rev)  | 0.05         | 0.1          | 0.15         |

**Figure 2.** Illustration of drilled FML.

#### 2.3. Tensile test

Tensile test experimental in which the specimen is mounted on 100kN Instron universal testing machine at a constant loading rate of 2mm/min complied with ASTM D3039 standard for tensile testing. The drilled hole was positioned in between of the extensometer pins. Each specimen was repeated three times to ensure the repeatability of test results and the average of obtained results were used for further analysis.

#### 3. Result and discussion

In this study, the tensile behaviour of fibre reinforced epoxy resin-based fibre metal laminates subject to tensile loading were determined at different spindle speed of (1050, 2020 and 2750 rpm) and also at different feed rate of (0.05, 0.10 and 0.15 mm/rev) as shown in Figure 3.

**Figure 3.** Maximum tensile stress obtained for 3A2F and 3A4F Fibre Metal Laminates (FML) at different spindle speed and feed rate.
From Figure 3, in sample 3A4F, at a constant speed of 1050 rpm, the maximum tensile stress value was reduced by 2.34% when the feed rate was increased from 0.05 mm/rev to 0.10 mm/rev. Meanwhile, by increasing the feed rate from 0.10 mm/rev to 0.15 mm/rev, drastic reduction of 46.23% for maximum tensile stress value of FML has occurred. This also resulted at spindle speed of 2020 rpm and 2750 rpm with 49.57% and 51.50% respectively. Moreover, at constant feed rate of 0.05 mm/rev, by increasing the spindle speed from 1050 rpm to 2020 rpm, the maximum tensile stress has been reduced by 2.12% only while when the spindle speed was increased by 2020 rpm to 2750 rpm, the maximum tensile stress value has been reduced by 3.53 %. Therefore, it can be discussed that in 3A2F FML, the increasing of spindle speed and feed rate only give a small reduction percentage to the maximum stress of the FML.

According to Figure 3 also, for 3A2F, at a constant spindle speed of 1050 rpm, when the feed rate was increased from 0.05 mm/rev to 0.10 mm/rev, maximum tensile stress value was reduced by 3.28%. Then, by increasing the feed rate from 0.10 mm/rev to 0.15 mm/rev, the residual stress has decreased by 3.39%. The percentage of decrement for 1050 rpm at different feed rate were almost equal. Besides, at constant feed rate of 0.05 mm/rev, the maximum tensile stress has decreased by 4.08% when the spindle speed was increased from 1050 rpm to 2020 rpm. When increasing the spindle speed from 2020 rpm to 2750 rpm, the maximum tensile stress of FML is deducted by 4.26%.

Overall, the highest tensile stress value was obtained at the lowest range value which are 1050 rpm of spindle speed and 0.05 mm/rev of feed rate for both 3A2F and 3A4F. In comparison, the 3A4F maximum tensile stress value were bigger than in 3A2F. This is because, 3A4F is thicker than 3A2F. It contained much more fibre than in 3A2F. Hence, more load needed to break the sample. Plus, the load is distributed to bigger surface area. In additional, the reduction of maximum tensile stress due to increase in spindle speed and feed rate was because the stress cannot be transferred from outer plies to inner plies due to delamination. Delamination around the drilled hole fails to transfer stress from plies to plies causing major lost in overall stiffness [7]. Hence, the stress concentration is more severe in outer plies and lead to an early damage to the structure.

![Microstructure of 3A4F](image)

**Figure 4.** Microstructure of 3A4F: (a) sample S1F1 (b) sample S1F3

From both Figure 4 (a) and (b), it has been noticed that the fibre breakages and matrix cracking are occurred more in S1F3 than the S1F1 of 3A4F specimen. This is due to the premature damage occurred during drilling and the application of the load applied during tensile test. From the defects happened in S1F3, it can be justified that the drastic reduction of residual strength obtained as spindle speed and feed rate were increased are due to the following defects. Plus, in drilling of composite materials, the temperature created while drilling the aluminium was higher at aluminium layer especially at high speed which has occurred in S1F3 where the speed was at maximum range.
The high temperature tool due to contact between aluminium and drill then made contact with GFRP panel made the fibre and matrix as a paste and spread it around [8].

4. Conclusion
In this study, fibre reinforced epoxy resin-based fibre metal laminates subjected to static tensile loading was studied experimentally. Several samples were prepared and drilled using HSS drill at different drilling parameter which are spindle speed and feed rate. Then, all the sample are analysed under static loading. It has found that the spindle speed and the feed rate are affecting the tensile behaviour of the FML. The obtained results for the maximum tensile stress show that the lower spindle speed and feed rate give greater strength to the FML structure. The thickness of the FML also plays a role in determining the strength of the drilled FML in which the thicker structure provide better maximum tensile stress to the structure.

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