An investigation into the effect of different patch variables on the impact performance of repaired CFRPs

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Abstract. Aircraft technologies and materials have been developing and improving drastically over the last hundred years. Over the last three decades, an interest in the use of composites for the external structures has become prominent. For this to be possible, thorough research on the performance of composite materials, specifically the impact performance, is required. Previous research of impact testing for pristine carbon fibre reinforced epoxy composites describes matrix cracks, fibre fracture and delamination as the failure modes that require monitoring. This damage is undesirable as the residual strength of the material is drastically reduced, thus affecting the performance if impacted again. To restore the mechanical properties after impact, a repair can be carried out and the two most common techniques are scarf and patch repairs, the latter of which will be the focus of this paper. Central patch repairs with varying features, such as the patch diameter and thickness, were impacted at an energy of 7.5J and the load-time and load-displacement traces were analysed as well as the damage area after impact. It was seen that increasing the patch diameter from 55mm to 65mm had little to no effect on the repair performance, suggesting that a difference of 10mm when repairing a 40mm hole is not sufficient to consider this variable. Furthermore, the addition of a plug greatly increased the stiffness, as did doubling the patch thickness, with panels that had a plug giving a maximum load of around 3000N more than that of a pristine panel. Additionally, the repairs that used a plug and a thin patch gave a damage area in the patch of about 70% less than was observed in a pristine panel. Overall, the results suggest that the patch repair technique, depending on the variables chosen, is effective at restoring the impact properties of carbon fibre reinforced epoxy composite materials.

Introduction

When considering the performance of composite materials for aircraft, the impact performance of repaired composites is critical because the residual strength of the material is significantly reduced after damage. Clark et al. found that damaged panels loaded under compression-based fatigue experienced an increase in the damage area [1]. This implies that impact damage is likely to lead to failure from fatigue if it does not fail immediately, highlighting the importance of researching how to effectively repair these composite materials. The two most common repair techniques are patch and scarf repairs, with this paper focusing on the former. Baker et al. found that single patch repairs effectively transfer loads from the patch itself to the undamaged parent material, allowing the repair to be successful. Furthermore, the join between the patch and parent material is lightweight and so does not cause significant stress concentrations, unlike the cut-outs required for scarf repairs [2]. However, the aerodynamics of the component remain more or less unchanged with scarf repair, whereas the patch repair technique has much more of an effect [2,3]. Considering the patch properties, research performed on the shape of the patch suggests that a circular patch is the most effective at reducing the damage from an impact [4] and, with regards to the lay-up of the patch, the response of the repair depends on the mechanical properties of the patch as well as the configuration [5]. In this paper, patch properties, such as the diameter and thickness, and how they affect the overall performance will be considered.

Impacting Patch Repaired Samples

Materials and Equipment. The samples used for this research were quasi-isotropic carbon fibre reinforced epoxy composites made from unidirectional prepreg with T700 fibres, cured using an autoclave and cut according to ASTM D7136 [6]. The lay-up used was $[45_2/\text{-}45_2/0_2/90_2]_s$, giving a final sample size of 100 x 150 x 4.58mm^3. The samples were repaired by removing a 40mm diameter disk from the centre of the panel and a patch was then adhered over this using a 0.25mm layer of MTFA-500 film adhesive. Two thicknesses of patch were used, with the thinner patch having a lay-up of $[45/\text{-}45/0/90]_s$, giving a thickness of 2.29mm, and the thicker patch being the same lay-up as the parent material. Additionally, some repairs were made with a push-fit plug of the parent material. The samples were tested under low-velocity impact loading using a drop weight tower with a 16mm diameter, round-nosed impactor and an impact energy of 7.5J. The force, displacement and time data was recorded and impacted samples were inspected using ultrasonic c-scanning equipment, allowing the damage area to be calculated.

Varying Patch Diameter. A 55mm patch was compared with a 65mm patch, both of which had a thickness of 2.29mm and used a plug. Fig. 1 shows the c-scan images of the damage in the 55mm and 65mm patches compared to that of a pristine panel. It is clear that the damage area is drastically reduced when a repair has been performed, which demonstrates the effectiveness of patch repairs. It can be seen that there is only a marginal difference between the results for the 55mm and 65mm patches, implying that patch size, or at least varying it by only 10mm for this size hole, has minimal to no effect on the performance of the repair.

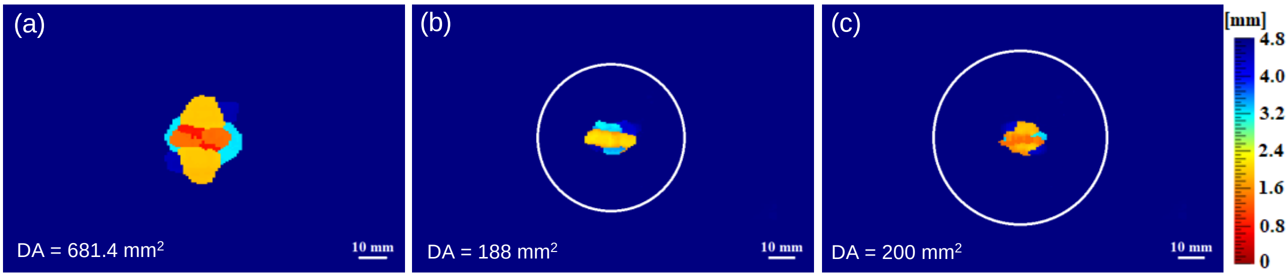

Figure 1. C-scan images after 7.5J impact of (a) pristine sample, (b) 55mm patch repair, and (c) 65mm patch repair

Varying Patch Thickness. Another variable in patch repairs that was considered was the patch thickness, with two different thickness being tested. The patch diameter used for this testing was 65mm and the samples had no plug. Fig. 2 shows the load-time and load-displacement traces for the thick (yellow line) and thin (orange line) patch repairs compared to a pristine sample (turquoise line). It can be seen that, with a thick patch, the impact performance is very similar to that of a pristine panel, whereas the thin patch results in lower stiffness. Additionally, the thick patch sample has the largest drop in load after damage initiation, likely due to the compression of the adhesive layer.

Comparing Plug and No Plug. The final variable considered in this paper is comparing repairs with a plug to those without. For this testing, thin patches were used with diameters of 55mm and 65mm. The load-time and load-displacement traces are shown in Fig. 2, which imply that the addition of a plug increases the stiffness and the maximum load the sample can withstand before damage occurs. The repair with a plug has the largest drop in load after damage initiation and the change in gradient once damage has initiated occurs around 1500N, 4500N and 8000N for the no plug repair, pristine and plug repair samples, respectively.

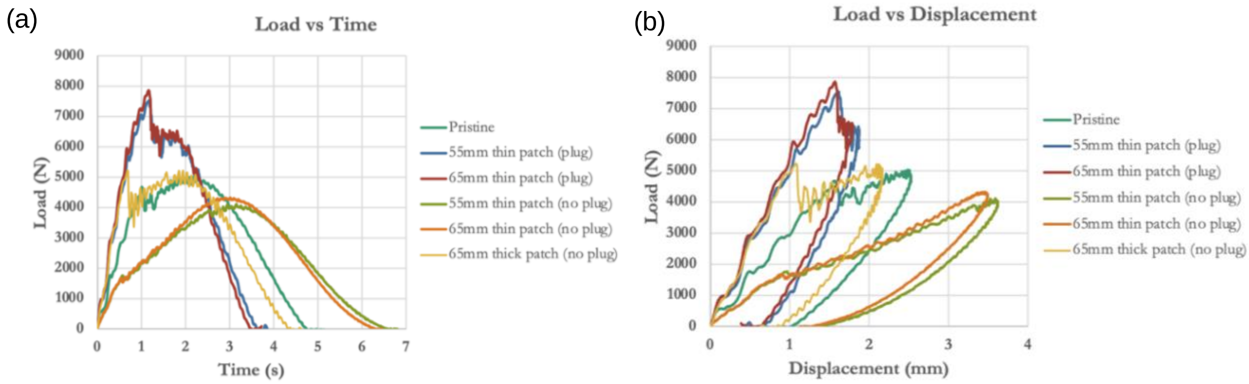

Figure 2: (a) Load vs time trace, and (b) load vs displacement trace for pristine, 55mm thin patch with plug, 65mm thin patch with plug, 55mm thin patch without plug, 65mm thin patch without plug and 65mm thick patch without plug repaired samples impacted at 7.5J

Conclusion

In conclusion, a patch repair is an effective and beneficial technique to resolve damage in composite materials. This can be seen because, when a patch repair is performed, the damage area is smaller than that observed in a pristine panel. The thickness of the patch and the addition of a plug greatly affect the impact performance of the composite by stiffening the structure, whereas the patch diameter has a limited effect. Future work on this subject area could include further investigating the effect of the thickness and inclusion of a plug through experimental or modelling work. Alternatively, different variables, such as the shape and lay-up of the patch or the adhesive thickness could be considered.

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