Analysis of the Effectiveness of Cold Expansion in Multi-Layer Stacks Using Digital Image Correlation

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Abstract. In the experimental study presented, the application of split-sleeve cold expansion to a multi-layer stack has been investigated. Digital image correlation was employed to determine the plastic zone developed around the expanded hole in individual layers of the stack. The results show that stacking offers some improvement in the split-sleeve cold expansion of thin specimens by causing the hole expansion to be more axisymmetric. However, the size of the plastic zone developed in individual layers of the stack is still smaller in comparison to one developed in a single specimen, which is equivalent in thickness to the multi-layer stack.

Introduction

Millions of holes are required to be drilled in aircraft structures during assembly. The enhancement of the fatigue performance of these structures involves the passage of a mandrel with an oversized head, pre-fitted with an internally lubricated split sleeve, through such holes. This causes the hole to plastically expand creating a ring of compressive residual stresses around the hole edge upon mandrel removal. One such commonly used process, called split-sleeve cold expansion, was developed by The Boeing Company in the 1960s and is currently being marketed by the Fatigue Technology Incorporated (FTI), USA [1]. In a recent article by the authors [2], a methodology was reported which has been developed utilising digital image correlation (DIC) to determine the size and shape of the plastic zone developed around the hole as a result of split-sleeve cold expansion. The plastic zone size is an indication of the effectiveness of the cold expansion process. The development of larger plastic zone results in a higher spring-back force from the elastic material surrounding the plastically deformed material, thus, creating a more compressive residual elastic stress field.

Most of the holes drilled in an aircraft structure are associated with the joints connecting two or more layers of material together. Despite significant relevance to the aerospace industry, the application of cold expansion to multi-layer stacks has received little attention by researchers. The focus of research, so far, has been primarily on the effect of fretting on the fatigue performance of bolted or riveted lap joints with joint holes previously cold-expanded. This paper presents an experimental investigation in which the methodology developed previously by the authors [2] has been extended to analyse the split-sleeve cold expansion of multi-layer stacks. The two key objectives of this work were (1) to establish whether the individual layers in the stack expand identically as a monolithic layer of equivalent thickness to the stack and (2) to determine if stacking improves the effectiveness of cold expansion in thin layers.

Experimental Procedure

A total of six rectangular specimens were machined from a 1.6mm thick 2024-T3 aluminium sheet and one from a 8 mm thick 2024-T351 aluminium plate with dimensions of 38×203 mm^2. A central hole of 6.36mm diameter was drilled in all of the specimens. The area around the hole on both faces of every specimen was painted with a matt-white paint before being painted with black speckles. Altogether, three split-sleeve cold expansion experiments were performed. The combination of an oversized mandrel head and split sleeve provided a total hole interference of approximately 4.6%. In the first experiment, cold expansion was performed on a multi-layer stack comprising of five thin specimens giving a combined thickness of 8mm. In the second and third experiments, cold expansion was performed on single thin and thick specimens, respectively. The sequential steps followed to obtain the displacement fields around the cold-expanded hole on both the faces of the specimens were to: (1) place the specimen in a specifically designed holder to acquire the initial image using a stereo-vision setup; (2) flip the specimen to obtain initial image of the opposite face; (3) perform split-sleeve cold expansion either as a single specimen or as part of a multi-layer stack; and (4) place the specimen back in the holder to obtain final images of both the faces of the expanded hole. The correlation between the corresponding initial and the final images were performed using the DIC software, ISTRA (Dantec Dynamics, Germany). The von Mises yield criterion was applied to the evaluated maximum and minimum principal strain fields to identify the plastic zone developed around the cold-expanded hole.

Experiment Results and Discussion

Figure 1 shows a comparison of the plastic zone shapes on the mandrel entry and exit faces for the single thin and thick specimens. The mandrel entry and exit faces refer to the specimen faces from which the mandrel enters or leaves the specimen, respectively, during cold expansion. The plastic zone for the thin specimen is smaller in size and highly non-axisymmetric implying that the split-sleeve cold expansion is not very effective in creating a uniform compressive residual stress field around the expanded hole in thin as it is in the thick specimens. The primary reason for this behaviour is localised warping in the thin specimen close to the hole edge which was not observed in the thick specimen. The plastic zone shapes for the five thin specimens comprising the multi-layer stack are shown in Figure 2. These plastic zone shapes are much more axisymmetric in comparison to the plastic zone developed during cold expansion of the single thin specimen in Figure 1, which indicates that the stacking improves the cold expansion of fastener holes in thin specimens forming the layers in a stack. However, the size of these plastic zones is still quite small in comparison to the plastic zone developed in the single thick specimen, which is equivalent in thickness to the stack. The variation in the shapes and sizes of the plastic zones between individual layers of the stack can also be seen in Figure 2. This establishes that multi-layer stack does not expand as a monolithic layer of equivalent thickness during split-sleeve cold expansion.

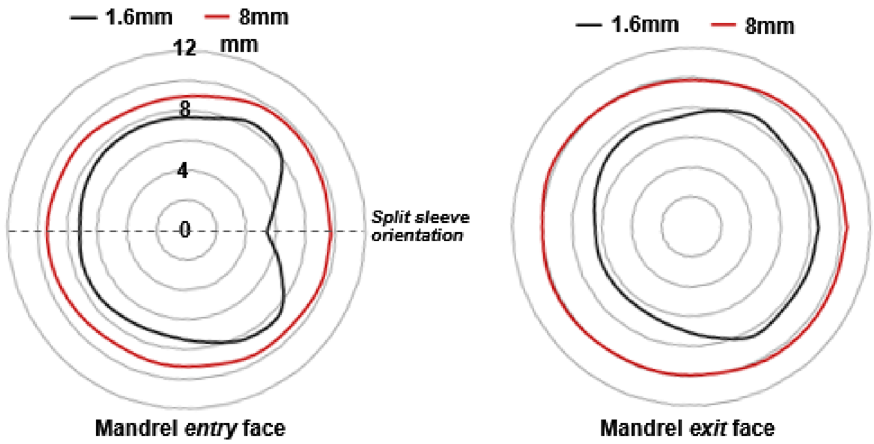

Figure 1 Plots of the shape of plastic zone for 1.6mm and 8mm thick specimens on the mandrel ***entry*** faces (Left) and the mandrel ***exit*** faces (Right)

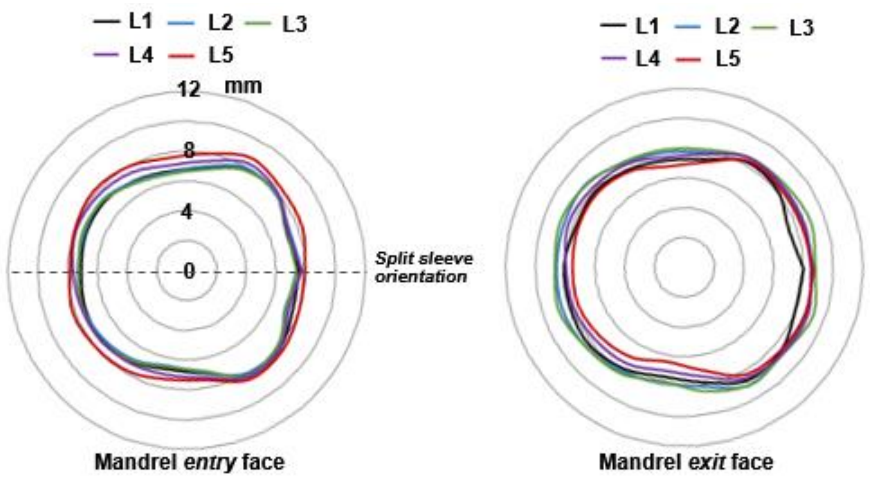

Figure 2 Plots of the shape of plastic zone for multi-layer stack comprising of five 1.6mm thick specimens (L1-L5) on the mandrel ***entry*** faces (Left) and the mandrel ***exit*** faces (Right). During cold expansion, mandrel was sequentially passed through five layers of the stack, entering from L1 and leaving from L5.

References

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