Fatigue life enhancement due to overloading

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Key words: Fatigue crack Growth, Cold work, Fracture, Fatigue life, Over loading

Introduction

The technique of cold working of fastener holes has received wide practice aerospace industry to increase the fatigue performance of components. A typical cold working technique involves drawing an oversized mandrel through a hole before the fastener installation. The main idea of cold expansion is to permanently induce a region of beneficial compressive residual stress around the hole. When the components with cold expanded holes are subjected to fatigue loading, the compressive residual stress counteract the damaging effect of high stress, by lowering the effective stress concentrating around the hole edge. A similar but simpler effect of residual stress formation can be achieved by pre-loading a plain hole specimen in tension, and subsequently release the specimen from the pre-load. Upon unloading, a considerable amount the compressive residual stress field is formed at the edge of the hole. This article reports the experimental findings of the fatigue improvement achieved when a specimen with hole is initially pre-stressed before it is fatigue cycled under constant amplitude loading. The cold working and overloading process on the specimen is firstly described. The material used and specimen fabrication were also explained. Furthermore, the experimental testing and technique giving the details of fatigue design were presented. The fatigue results were given in S-N curve and in terms of fatigue life improvement factor (LIF) to compare the individual and overall performance of each type of specimens.

Materials and Methods

The aerospace grade rolled sheets of 2024 -T351 aluminium alloy were used in the as received condition with thickness of 6.40 mm for making the specimens. For cold working specimens a central pilot hole of 5.3 mm diameter was first drilled and then enlarged using a cobalt coated starting reamer of 5.8 mm diameter with lubricant followed by a reamer of 6.0 mm diameter. A total of twenty four specimens with 6mm diameter hole in the center of the specimen were fabricated. The tensile tests were carried out on plate specimens fabricated with its axis parallel to the rolling direction giving mechanical properties of the material used in this investigation. The cold expansion of 3.6%, 5.6% and 7.6% were applied to the specimens using a in-house designed cold working rig mounted on 50 tonnes Li-Chin Hydraulic press machine. The cold worked specimens were overloaded with displacement rate of 0.01mm/sec to 65% and 75% of material yield stress, using 100kN MTS 810 Servo-hydraulic Material Test System. The crack initiation and its measurement were carried out using video microscope. The maximum load corresponding to one third of yield stress of the material was applied to the specimen. The fatigue tests were carried out at 10Hz frequency at room temperature. The fatigue testing was ended whenever a specimen was totally fractured into two pieces, or the fatigue life exceeded 1.5×10^5 cycles with condition that no crack initiated at the hole edge. The two un-worked specimens with 6mm diameter hole each were tested at 139 MPA, 168 MPa, and 211MPa with stress ratio R = 0.1 to establish a baseline fatigue life data. These baseline data of plain hole specimen were used to justify the effectiveness of the two pre-stressing techniques one cold working and cold working with overload in terms of their improved fatigue life. Next, one specimen each was tested for cold expansion of 3.6%, 5.6% and 7.6% at all the stress ratios of R=0.1, R=0.5, R=0.5 and R=0.7. Cold worked and subsequently overloaded specimens with central hole with 65% and 75% overload were tested for stress ratios, R of 0.1,0.3, and 0.5 at maximum stress of 211 MPa.

Results and Discussion

The two fatigue tests each for un-worked specimens were carried out at three stress levels of 139 MPA, 168 MPa, and 211MPa and are plotted on log-log scale. Three stress levels and six specimens were used to generate the S-N diagrams. As the majority of tests were conducted at a stress level of 211MPa the base line comparison data interms of life was obtained. The specimens H1 and A3 were failed at 19620 cycles and 20643 cycles respectively. Since majority of the tests (89%) were conducted under S_{max} = 211 MPa, hence the average life of specimen H1 and A3 can provide reasonable basis of comparison. The average life of these to specimens is 20132 cycles and it is considered as the base line fatigue life of the un-worked specimens tested at 211 MPa. The fatigue tests were also carried out at stress ratio, R of 0.1, 0.3 and 0.5 and their life are 13648 cycles, 19899 cycles, and 62022 cycles respectively. These tests are carried out with samples with 10 mm diameter hole. It is observed that the specimens with larger stress ratio, R has a larger life. The life to failure increases as the stress ratio increases.

The 3.6%, 5.6% and 7.6% cold-work specimens were tested with stress ratios of 0.1, 0.3, 0.5, and 0.7 at 211 MPa. The fatigue life of 3.6% cold worked group of specimens show the fatigue life improvement of about 3 times as compared to the un-worked samples for stress ratio, R in the range of 0.1 to 0.5 whereas for the stress ratio of 0.7 the life improvement is more than 50 time and the specimen did not fail at all. For 5.6% and 7.6% cold worked group of specimens also the improvement in life is observed with increase in stress ratio. Moreover, at lowest R = 0.1 the 7.6% cold expanded specimen reveals superiority in fatigue life than other cold-work group of specimens. However at stress ratio, R = 0.7 for all levels of cold expansion/ cold work the specimens did not fail even at 1.5 x10^6 cycles and at the same time crack nucleation around the hole edge were not observed with 1000 X magnification using video microscope. In general, 7.6% cold expansion group produced highest fatigue life enhancement for present material, and this could be considered as a promising candidate for actual applications in aerospace structures. Pre-stressing method by overloading (OL) of specimen produces similar improvement in fatigue life. Comparatively less data scatter was observed for both 65% and 75% overloaded specimens. With 75% tensile overloading higher life improvement than 65% overloading has been observed.

Conclusions

Fatigue life of the specimens with cold worked improves significantly.
The improvement in fatigue life is highest for the 7.6% cold work specimens as compared to un-worked specimens.
Fatigue life improvement with stress ratio, R of 0.1,0.3,and 0.5 is practically same but it is considerably higher for stress ratio, R of o.7.
The fatigue life improvement has been observed in case of overloading also and the life improvement is more as overloading increases.
The improvement in the high cycle fatigue region is more than 50 times and shows the promise of cold-working as well as overloading process.

Benefits from the study

The cold working and overloading process has shown an considerable improvement in fatigue life and this can be addition to the knowledge for the design development process for the aircraft components subjected.
A number of papers have been published in the journals.
No. of post graduate students have been benefited in their research work.
The study can lead to development of commercial cold-working rig for aerospace applications but it needs additional resources.

Patent(s), if applicable:

Not any

Stage of Commercialization, if applicable:

If additional funding provided it may lead to a commercial cold working rig for aerospace applications

Project Publications in Refereed Journals

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Name of Graduate	Research Topic	Field of Expertise	Degree Awarded	Graduation Year
Abdalla A Ab Rashdi	Finite element evaluation of elasto-plastic residual stresses around cold worked fastner holes	Aerospace Engineering	MSc.	2000

IRPA Project number: 03-02-04-0089
UPM Research Cluster: SSH