# EFFECT OF COLD WORK AND OVERLOAD ON FATIGUE LIFE OF NOTCHED 2024-T351 ALUMINIUM ALLOY SPECIMENS

**Prithvi Raj Arora , Jeffrey Tan Meng Lee, P. Edi, and M. Saleem**
*Department of Aerospace Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor.*

## *ABSTRACT*

*Fatigue life of the notched circular hole 2024-T351 aluminium alloy specimens improves significantly with cold work and the improvement in fatigue life is highest for the 7.6% cold work specimens as compared to un-worked specimens. The improvement in fatigue life 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 0.7. The fatigue life improvement has been observed in the case of overloading also and the life improvement increases 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. 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 times and the specimen did not fail at all. For both the overload specimens the improvement in life increases with increase in stress ratio. With 75% tensile overloading, life improvement higher than 65% overloading has been observed. An improvement factor in life is maximum for R = 0.5 for both the overloads and their values are 4.1 and 5.3 for overload of 65% and 75% respectively.*

**Keywords :** *Aluminium Alloy, Cold working, Fatigue, Life, Overload*

## 1.0 INTRODUCTION

The circular holes are major sources of fatigue cracking in aircraft structures. The failures around/from the nearby material starts under the influence of the stress concentration. Residual stresses can have a significant influence on the fatigue lives of machine components [1-10]. In particular near surface tensile residual stresses tend to accelerate the initiation and growth phases of the fatigue process while the compressive residual stresses close to the surface may prolong the fatigue life. To avoid such failures the region around the hole should be strengthened to delay the nucleation and crack propagation leading to final failures. One approach to avoid failures is to plastically deform the material face of the component adjacent to the hole and the other is to impart the radial expansion of the material adjacent to the hole along its entire periphery. Residual stresses can be introduced into the components by forging, bending and welding operations, which may be employed during manufacturing or by forces and thermal gradients imposed during their usage. Many methods are used to strengthen the material around the hole region and are classed under the deliberate generation of residual stresses e.g. shot peening, hammer peening, cold rolling, other cold working methods, and intentional overloads [1-10]. In aerospace industry the cold expansion is a widely used technique to obtain fatigue life enhancement of initially uncracked hole specimens. A typical cold working process involves drawing an oversized mandrel through a hole in the plates before the installation of fasteners. The main idea of cold expansion is to introduce a compressive residual stress around the hole region permanently. When the components with cold expanded holes are subjected to fatigue loading, the compressive residual stress present around the hole region counteracts the damaging effect of cyclic stresses by lowering the effective stress concentration due to the hole [7-8, 12-15]. A similar but simpler effect of residual stress formation can be achieved by pre-loading a plain hole specimen in tension by a specified amount of overload, and subsequently release the specimen from this overload. Upon unloading, a considerable amount the compressive residual stress field is formed at the edge of the hole.

This investigation reports the experimental findings of the fatigue life improvement in a very frequently used aircraft body skin material 2024-T351 aluminium alloy due to cold working and overloading processes. The effect of stress ratio on the fatigue life improvement is also studied.

.

## 2.0 MATERIALS AND EXPERIMENTAL PROCEDURES

### Material, specimen, and test details:

The aerospace grade rolled sheets of 2024 -T351 aluminium alloy was used in the as received condition with thickness of 6.40 mm for making the specimens. The specimen blanks have been cut along the rolling direction. The tensile tests were carried out on plate specimens with its axis parallel to the rolling direction. The mechanical properties of 2024-T351 aluminium alloy plate material tested at room temperature are

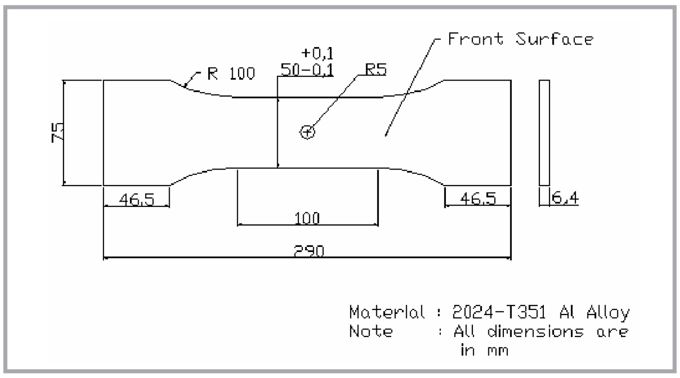

***Figure 1: Dimensions of 2024-T351 aluminium alloy specimen***

given in Table 1. The geometrical details of the specimen with a hole at the center are shown in Figure 1. For cold working a central pilot hole of 5.3 mm diameter was first drilled in the specimen 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 6 mm diameter hole in the center of the specimen were fabricated.

***Table 1a: Chemical composition limits of 2024 aluminium alloy***

| Chemical Composition (Weight)% | **Al** | **Si** | **Fe** | **Cu** | **Mn** | **Mg** | **Cr** | **Zn** | **Ti** |
|---|---|---|---|---|---|---|---|---|---|
| | Approx. 93.5 | 0.05 max | 3.8 4.9 | 0.3- 0.9 | 1.2- 1.8 | 0.1 max | 0.25 max | 0.15 max | 0.05 max |

***Table 1b: Mechanical properties of A1 2024-T351 alluminium alloy***

| | |
|---|---|
| Young's Modulus, $E$ | 71539.2 MPa |
| Yield strength, $\sigma_y$ (0.1%) | 421.2 MPa |
| Ultimate strength, $\sigma_{ut}$ | 633.2 MPa |
| Strain hardening exponent, $n$ | 0.1561 |
| Strain hardening coefficient, $K$ | 797.83 MPa |

The cold expansion of 3.6%, 5.6% and 7.6% were applied to the specimens using an in-house designed cold working rig mounted on 50 tonnes Li-Chin Hydraulic press machine (Figure 2). The dimensions of the mandrel and hole diameters used for cold work are given in Table 2. The specimens were overloaded with displacement rate of 0.01mm/sec to 65% and 75% of material yield stress, using 100 kN MTS 810 Servo-hydraulic Material Test System (Figure 3). 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 1.5 106 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 211 MPa 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 the other overloading with a single 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=0.3, R=0.5 and R=0.7 (Table 3, 4). Cold worked and 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.

***Figure 2: Cold working rig mounted over the press***

***Table 2: Details of cold expansion design***

| Cold Working % | Starting Hole Diameter, *SHD* (mm) | Mandrel Major Diameter, *D* (mm) | Sleeve Thickness, *t* (mm) |
|---|---|---|---|
| 3.6 | 6.005 | 5.816 | 0.203 |
| 5.6 | | 5.936 | |
| 7.6 | | 6.056 | |

***Figure 3: Material Testing System (MTS) machine***

## Cold Working

During the cold working process the material around the hole region is expanded (Figure 4a). The cold working process introduces compressive tangential residual stresses ahead the edge of the hole. The percent cold work (%CW) is defined as follows,

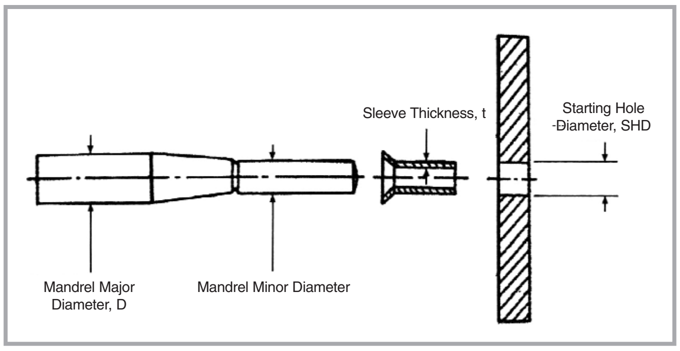

***Figure 4a: Schematic dimensions to determine amount of cold working of hole***

$$\% \text{ CW} = \left[\frac{D + 2t - d}{d}\right] \text{x } 100 \tag{1}$$

where D is the diameter of the mandrel and
d is the initial diameter of the hole
t is the thickness of the sleeve

The other details about the cold working process and finite element analysis are given elsewhere [16].

## Overloading Process

The overloading is carried out by applying a load, at the end of the plate specimen, more than a load which will just induce plastic deformation at the hole edge e.g. corresponding to more than 1/3 $\sigma_y$ of the material used. The specimen is subsequently unloaded from overloading stress $\sigma_{OL}$, giving residual stress

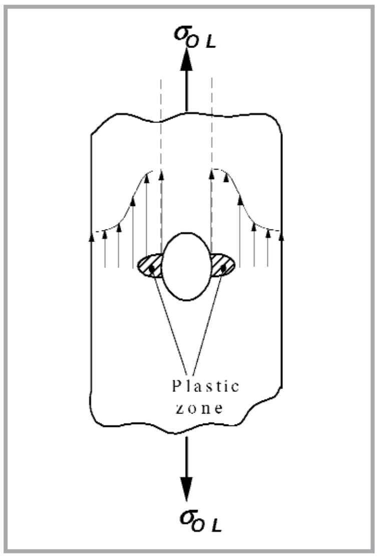

***Figure 4b: Schematic of Plastic deformation around the hole edge during the overloading process***

distribution around the edge of the hole simultaneously at two local areas perpendicular to the direction of the applied stress (Figure 4b). The overloading stress sOL [16] is defined by the following equation

$$\text{Overloading} = \frac{\sigma_{OL}}{\sigma_y} \text{ x } 100\% \qquad (2)$$

where, $\sigma_y$ is the yield stress of the material
$\sigma_{OL}$ is the stress used for overload calculation

(1/3 $\sigma_y$ applied at the end of the specimen corresponds to just yield of material at the hole edge and it also corresponds to a stress concentration factor of 3.0)

***Table3: Fatigue test conditions of plain/cold worked/ overloaded hole specimens***

| No. | Specimen | *SHD* (mm) | Hole Condition | Fatigue test condition $f = 10$ Hz | | |
|---|---|---|---|---|---|---|
| | | | | $\sigma_{max}$ (MPa) | $R = \sigma_{min}/\sigma_{max}$ | $\sigma_{max}/\sigma_y$ |
| 1 | D1 | 6 | Not cold worked | 139 | 0.1 | 0.33 |
| 2 | E1 | | | | | |
| 3 | F1 | | | 168 | | 0.40 |
| 4 | G1 | | | | | |
| 5 | H1 | | | 211 | | 0.50 |
| 6 | A3 | | | | | |
| 7 | M1 | 10 | | | 0.1 | |
| 8 | M2 | | | | 0.3 | |
| 9 | M3 | | | | 0.5 | |
| 10 | A1 | 6 | Cold Expanded (3.6%) | 211 | 0.1 | 0.50 |
| 11 | A4 | | | | 0.3 | |
| 12 | D6 | | | | 0.5 | |
| 13 | I1 | | | | 0.7 | |
| 14 | F6 | | Cold Expanded (5.6%) | | 0.1 | |
| 15 | B4 | | | | 0.3 | |
| 16 | D4 | | | | 0.5 | |
| 17 | E4 | | | | 0.7 | |
| 18 | E2 | | Cold Expanded (7.6%) | | 0.1 | |
| 19 | G6 | | | | 0.3 | |
| 20 | B3 | | | | 0.5 | |
| 21 | C6 | | | | 0.7 | |
| 22 | D5 | | Overloaded (65%) | | 0.1 | |
| 23 | D7 | | | | 0.3 | |
| 24 | F3 | | | | 0.5 | |
| 25 | A2 | | Overloaded (75%) | | 0.1 | |
| 26 | A7 | | | | 0.3 | |
| 27 | E5 | | | | 0.5 | |

## RESULTS AND DISCUSSIONS

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 (Figure 5). 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 in terms of life was obtained. The specimens H1 and A3 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 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

***Table4: Fatigue test results for different loading conditions***

| No. | Specimen | | | Cycles to failure $N_f$ | Life Improvement Factor, *LIF* | Fatigue test condition $f = 10$ Hz | |
|---|---|---|---|---|---|---|---|
| | | | | | | $\sigma_{max}$ (MPa) | $R = \sigma_{max}/\sigma_{min}$ |
| 1 | Plain (Baseline) | | D1 | 120 000 | 5.96 | 139 | 0.1 |
| 2 | | | E1 | 79 300 | 3.94 | | |
| 3 | | | F1 | 36 950 | 1.84 | 168 | |
| 4 | | | G1 | 55 077 | 2.74 | | |
| 5 | | | H1 | 19 620 | 0.97 | 211 | |
| 6 | | | A3 | 20 645 | 1.03 | | |
| 7 | | | M1 | 13648 | 0.68 | | 0.1 |
| 8 | | | M2 | 19899 | 0.99 | | 0.3 |
| 9 | | | M3 | 62022 | 3.08 | | 0.5 |
| 10 | Cold Expanded | 3.6% | A1 | 59 545 | 2.96 | | 0.1 |
| 11 | | | A4 | 57 610 | 2.86 | | 0.3 |
| 12 | | | D6 | 72 470 | 3.60 | | 0.5 |
| 13 | | | I1 | 1 500 000* | > 49.67 | | 0.7 |
| 14 | | 5.6% | F6 | 60 775 | 3.02 | | 0.1 |
| 15 | | | B4 | 78 860 | 3.92 | | 0.3 |
| 16 | | | D4 | 365 940 | 18.18 | | 0.5 |
| 17 | | | E4 | 1 500 000* | > 49.67 | | 0.7 |
| 18 | | 7.6% | E2 | 117 250 | 5.82 | | 0.1 |
| 19 | | | G6 | 154 211 | 7.66 | | 0.3 |
| 20 | | | B3 | 618 560 | 30.72 | | 0.5 |
| 21 | | | C6 | 1 500 000* | > 49.67 | | 0.7 |
| 22 | Overloaded | 65% | E4 | 35 210 | 1.75 | | 0.1 |
| 23 | | | E3 | 54 966 | 2.73 | | 0.3 |
| 24 | | | C2 | 82 389 | 4.09 | | 0.5 |
| 25 | | 75% | A6 | 47 780 | 2.37 | | 0.1 |
| 26 | | | G2 | 64 603 | 3.21 | | 0.3 |
| 27 | | | F5 | 107 102 | 5.32 | | 0.5 |

[1] Run out defined as no crack initiation or failure observed at 1.5 million cycles.
[2] Life improvement was compared with respect to the average $N_f$ of specimen H1 and A3, i.e. 20133 cycles

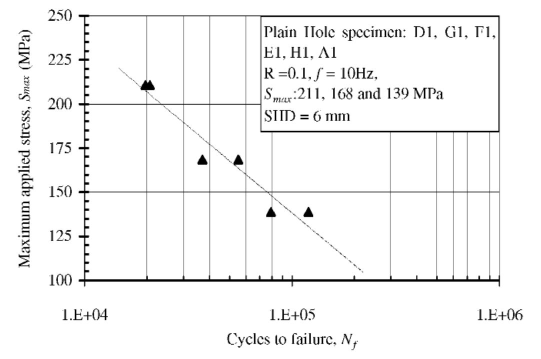

***Figure 5: S-N curve for 6mm plain hole specimens for three different maximum stress levels***

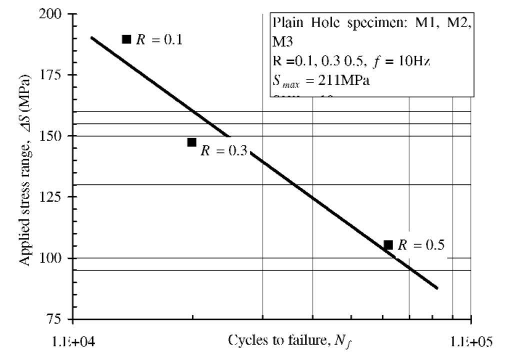

***Figure 6: S-N curve for 10 mm plain hole specimens for three different stress ratios R at common maximum stress $S_{max}$***

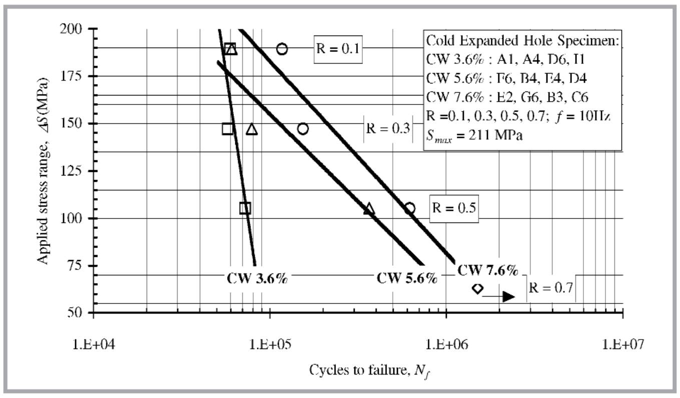

**Figure 7: S-N curve for 6 mm cold expanded hole specimens for four different stress ratios R at common maximum stress $S_{max}$**

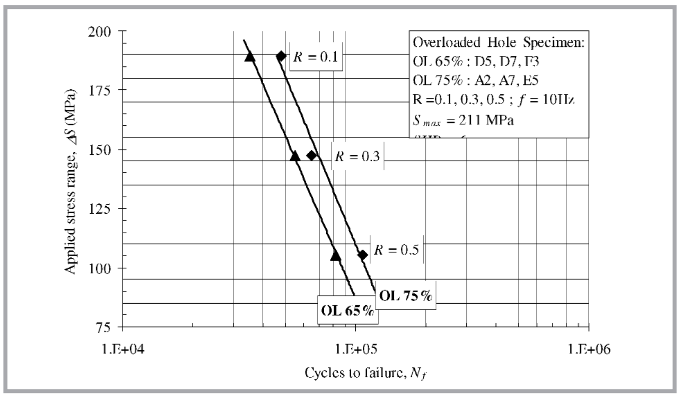

**Figure 8: S-N curves for 6 mm overloaded hole specimens for three different stress ratios R at common maximum stress $S_{max}$**

are 13648 cycles, 19899 cycles, and 62022 cycles respectively (Figure 6). These tests were carried out with samples with 10 mm diameter hole. It was observed that the specimens with larger stress ratio, R have 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 (Figure 7). 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. 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 x $10^6$ cycles and at the same time crack nucleation around the hole edge were not observed with 1000 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. Leon [17] have observed life improvement of 1.5 at 280 MPa (40 ksi) gross stress to 2.5 at 210 MPa (30 ksi) gross stress levels for 6061 aluminium alloy using split sleeve and split mandrel type of cold working process. Longer lives of specimens of two aluminium alloys with 4% cold expanded holes were obtained by Lacarac et al. [18] provided that the applied load ratio was less than 0.7, and the maximum applied stress was less than 0.5 of the yield strength. The decrease in fatigue crack growth in cold expanded specimens was related to higher crack opening stresses which is a consequence of the presence of compressive residual stresses arising from the cold expansion. Our results also support the assertion that the cold expansion gives rise to increase in fatigue life of the cold worked specimens. The improvement in life is much higher at lower stresses leading to baseline life more than $10^5$ cycles of life.

Pre-stressing method by overloading (OL) of specimen produces similar improvement in fatigue life. For each overload of 65%, and 75% one specimen is tested at stress ratio R= 0.1,0.3, and 0.5. The applied stress range versus life to failure has been plotted on semi log scale in Figure 8. At each stress ratio R of 0.1, 0.3, and 0.5 a comparatively less scatter in the life to failure data was observed for both 65% and 75% overloaded specimens. For both the overload specimens the improvement in life increases with increase in stress ratio. With 75% tensile overloading higher life improvement than 65% overloading has been observed. An improvement factor in life is maximum for R = 0.5 for both the overloads and their values are 4.1 and 5.3 for overload of 65% and 75% respectively.

For better comparison of the overall fatigue performance of all tests, the combined S-N curve for plain unworked, cold expanded and overloaded hole specimens for different stress ratios R, at common maximum stress $S_{max}$, has been given in Figure 9. Amongst the tests, plain hole specimens had the lowest fatigue survivability in contrast to their pre-stressed counterparts. The fatigue life of lowest 3.6% cold expansion, 65% and 75% overloaded specimens concentrated mainly on the cyclic region $3 \times 10^4 < N_f < 1 \times 10^5$ for three R ratios 0.1, 0.3, and 0.5. The present experimental data suggests that low R-ratios projecting highest detrimental effects on fatigue performance of all types of tests with constant maximum stress. However, the cold working process with 7.6% cold work gave the maximum life improvement as compared to base line data of unworked specimens.

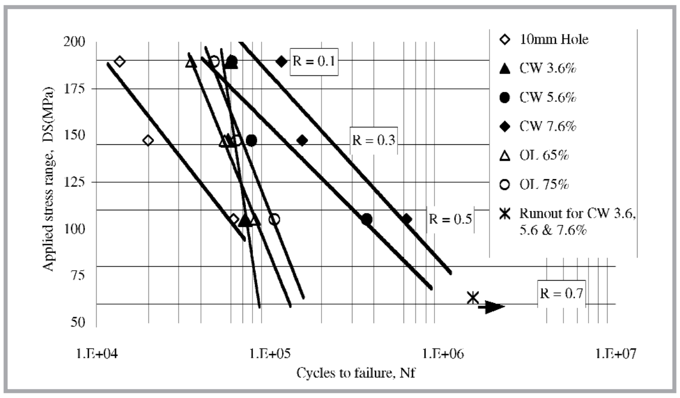

**Figure 9: Combined S-N curve for plain, cold expanded and overloaded hole specimens for different stress ratios R at common maximum stress $S_{max}$**

The nondimensional pressure corresponding to the cold work values used in this study has been evaluated and then the nondimensional tangential residual stress is obtained, using the finite element analysis results of Arora et al. [19]. The residual stresses for 3.6%, 5.6%, and 7.6% cold work are obtained as –568.6 MPa, -598 MPa, and -631.8 MPa respectively and are of compressive in nature. It is observed that the improvement in fatigue life is proportional to the amount of cold work. As the residual stress obtained for the cold work of 7.6% is –631.8 MPa, and is largest for the largest cold work, it proves the assertion that the life improvement is greatest for the largest cold work as it gives highest amount of compressive residual stress. On the other hand the residual stresses corresponding to 65%, and 75% over load are evaluated using the finite element analysis results of the related study about the effect of overload of Arora et. al. [16]. The residual stresses for the 65% overload and the 75% overload are –358Mpa and –484 MPa respectively. The size of elastic plastic boundary for 3.6%, 5.6%, and 7.6% cold work are 3.75 mm, 4.5 mm, and 4.95 mm from the edge of the hole whereas the elastic plastic boundary for 65% overload and 75% overload are 2 mm and 3 mm from the edge of the hole are obtained using the finite element analysis results of the present author [16, 19]. It is observed that the more distance of the elastic plastic boundary from the edge of the hole, the more is the residual stress at the edge of the hole and thereby it gives more fatigue life to failure. In view of this, following assertion is made.

The experimental results (Figure 9) shows that the life improvement for 65% over load and 75% overload is less as compared to the life improvement obtained through the cold working process of 5.6% and 7.6%. It is also observed experimentally that the life improvement is more if residual stress is more. On the basis of the results of this investigation it is concluded that the cold working process shows its superiority over the overloading process.

## CONCLUSIONS

Following are the conclusions drawn from the work carried out in the present investigation,

i. Fatigue life of the specimens improves significantly with cold worked.
ii. The improvement in fatigue life is highest for the 7.6% cold work specimens as compared to un-worked specimens.
iii. There is no improvement in fatigue life to failure for the stress ratio, R in the range of 0.1 to 0.5, however the fatigue life to failure increases considerably for a stress ratio, R of 0.7.
iv. The fatigue life improvement has also been observed in case of overloading and the life improvement is more as overloading increases.
v. 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.
vi. The cold working process is superior to the overloading process.

## ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support of the Ministry of Science, Technology and Innovation Malaysia (IRPA project No: 03-02-04-0089) for the provision of research grant for this work. ■

---

## REFERENCES

[1] E R Speakman, Fatigue life improvement through stress coining methods, Achievement of high fatigue resistance of metals and alloys, *ASTM STP No. 467*, p209-227, 1970.

[2] ASTM STP 1004, *Analytical and experimental methods for residual stress effects in fatigue*, Eds. R L Champoux, J H Underwood, and J A Kapp, 1988.

[3] G A Webster, ECRS-5, Holland, Sept. 1999. *Materials Science Forum*, 347-349,p 1-9, Trans Tech Publications, Switzerland, 2000.

[4] M R Ling, and J Schijve, The effect of intermediate heat treatments on overload induced retardations during fatigue crack growth in an al-alloy, Fatigue Fract. *Engng. Mater. Struct*., Vol 15, p 421-430, 1992.

[5] Du Bai-ping, Li Nian, and Wang Zhang-Zhong, Influence of mode-I, II, and III overloading on the fatigue threshold of mode I, *Int. J Fatigue*, Vol 16, p 315-320, 1994.

[6] J Shewchuk, Decreasing the fatigue strength reduction factor by dimpling, *J of Testing and Evaluation*, V2, p425-428, 1974.

[7] J L Phillips, Fatigue life improvement by sleeve cold working, *S A E Paper No. 730905*, 1973.

[8] J Schijve, F A Jacobs and A E Meulman, Flight simulation fatigue tests on lugs with hole expanded according to the split sleeve cold work method, Netherlands Natl Lucht-Ruimtevaartlab, *Rep. No. TR 78131 U,* 1978.

[9] J Y Mann, A S Machin, W F Lupson, and R A Pell, *Techniqes for increasing the fatigue life of thick section aluminium alloy bolted joints, Aluminium*, Vol 60, p515-520, 1984.

[10] R A Pell, P W Beaver, J Y Mann, and J G Sparrow, Fatigue of thick section cold expanded holes with and without cracks, *Fatigue Fract. Engng. Mater. Struct*. Vol 12, p 553-567, 1989.

[11] C P Stack, and R I Stephens, Effect of split sleeve cold expansion on the fatigue resistance of hot-rolled 1020 steel, *Int. J Fatigue*, Vol. 11, p327-334, 1989.

[12] R G Hocker and Split sleeve, cold worked holes in 7050-T73651 aluminium plate for improved fatigue life, *Northrop Corporation*, NOR 82-80, August, 1982.

[13] P R Arora, B Dattaguru, and Subramanya Hande, A method for estimation of the radius of elastic-plastic boundary around cold worked holes, Journal of Testing and Evaluation, *JTEVA*, Vol 20, p369-375, 1992.

[14] G J Petrak and R P Stewart, Retardation of cracks emanating from fastener holes, *Engng Fract Mech,* Vol 6, p275-282, 1974.

[15] P M Toor and Cracks emanating from precracked coldworked holes, *Engng Fract Mech*, Vol 8, p391-396, 1976.

[16] Prithvi Raj Arora, Jeffrey Tan Meng Lee, A M S Hamouda, S M Sapuan, ShahNor Basri, and Zairil Azhar Zaludin, Effect of Single Overload on stress distribution in an axially loaded 2024-T351-aluminium alloy plate specimen with a Hole, *Jurnal Mekanikal*, Dis. 2002, p 21-35.

[17] A. Leon, Benefits of split mandrel coldworking, Int. *Journal of Fatigue*, Vol 20, p1-8, 1998.

[18] V Lacarac, D J Smith, M J Pavier, M Priest, Fatigue crack growth from plain and cold expanded holes in aluminium alloys, *Int. Journal of Fatigue*, Vol 22, p189-203, 2000.

[19] Prithvi Raj Arora, Jeffrey Tan Meng Lee, Christian Barnard, and Waqar Asrar, Finite element analysis of residual stresses during cold working, *Jurnal Mekanikal*, June 2002, p 11-25.

## PROFILE

**Assoc. Prof. Dr Prithvi Raj Arora**
Aerospace Engineering Department,
Faculty of Engineering,
University Putra Malaysia ,
43400 Selangor, Serdang, D.E., Malaysia.
Phone: 603-8946 6404(O)
Fax: 603-8656 7125
Email: Prithvi@eng.upm.edu.my;
Prithviraj.arora@gmail.com

The author has obtained a B.Sc. Engineering degree (Mechanical) in 1966 from Jiwaji University, Gwalior (India). Subsequently earned M.Sc. (Faculty of Engineering) by thesis in 1970 and PhD (Faculty of Engineering) in 1985 by thesis both from Indian Institute of Science, Bangalore (India). The author has worked at Mechanical Engineering Department of Indian Institute of Science, Bangalore (India) from 1970 as Research Assistant to 1996 as Principal Research Scientist. His research areas of interest are Design of special purpose machines, Characterisation of materials, Fatigue and fracture mechanics, Failure analysis, and Stress analysis. The author has been working at Aerospace Engineering Department, Faculty of Engineering, University Putra Malaysia Since December 1996 as Associate Professor. Currently the author has been actively involved in the research related with Fretting Fatigue, Fracture Mechanics, and Characterisation of materials.

**Jeffrey Tan Meng Lee**
Aerospace Engineering Department,
Faculty of Engineering,
University Putra Malaysia ,
43400 Selangor, Serdang, D.E., Malaysia.

**Prasetyo Edi**
Aerospace Engineering Department,
Faculty of Engineering,
University Putra Malaysia ,
43400 Selangor, Serdang, D.E., Malaysia.

**M. Saleem**
Aerospace Engineering Department,
Faculty of Engineering,
University Putra Malaysia ,
43400 Selangor, Serdang, D.E., Malaysia.

### *ANNOUNCEMENT*

# APCChE Presidency now held by Malaysia, 2006 Congress to be hosted by KL

### 27 May – 1 June 2006

At the recently held APCChE 2004 Congress in Kitakyushu, Japan, the Council of the Asian Pacific Confederation of Chemical Engineers (APCChE), confirmed Ir Prof. Dr Mohd. Ali Hashim as President of its Council, effective from October 2004. He will hold this position until May 2006 when the next APCChE Congress is to be held in Kuala Lumpur.

The Institution of Engineers, Malaysia congratulates him on this prestigious appointment. The Presidency of the Asian Pacific Confederation of Chemical Engineers (APCChE) is traditionally held by the host country of the next Congress.

The 11th APCChE Congress will be held on 27 May – 1 June, 2006 and is expected to draw 1200 delegates from the Asia Pacific area and Europe. Congress preparations are now well under way. An exhibition will also be held alongside the Congress, and include a show-case of Malaysian Chemical Engineering achievement. A regional Chem-E-Car competition will also be held on the sidelines. Interested congress participants, sponsors and exhibitors can contact Puan Siti at IEM Secretariat (03-79684001/02) for details of the Congress, Exhibition and Showcase.