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DISCUSSION

A. Alpas[1] *and C. N. Reid*[1] (*written discussion*)—Examination of the surface of a hole cold expanded by the split sleeve process shows the presence of a step put in by the outer end of the spiral sleeve. The effect of the angular position of this step on the fatigue life of a cold expanded 6000 series aluminum alloy (British designation HE9) has been investigated, and the results obtained support the conclusions reported by the authors of this paper. Specimens containing a hole of 5-mm diameter drilled in their reduced gage section (100 by 19 by 1.67 mm) were solution treated at 520°C for 40 min, quenched, and then aged for 22 h at 170°C prior to cold expansion. During the cold expansion the position of the step was controlled and two orientations were used: (1) specimens with the angular position of the step coinciding with the longitudinal axis (designated the "12 o'clock" position) and (2) specimens with the angular position of the step in the transverse direction (the "3 o'clock" position). The amount of expansion was kept between 3 and 3.5%. Fatigue tests were conducted under a constant stress amplitude σ_a = 48 MPa and a stress ratio R = 0.05.

The fatigue lives of the specimens cold expanded at each of the step positions are summarized in Table 4. The table also includes the mean life of specimens subjected to an annealing treatment (170°C, 2 h) after the cold expansion. This was chosen to cause significant stress relief without overaging. Statistical analysis using the "Students's t test" showed that there is no significant difference between the mean lives of the two orientations of cold-worked specimens (t = 0.68). Similarly, there is no significant difference between the two orientations of stress-relieved test specimens, either (t = 0.65).

We conclude that the step constitutes an insignificant notch in the test piece. This is supported by the observation that in some of the CX3 and CXSR3 specimens, the fatigue crack did not even intersect the step. Furthermore, the first fatigue crack showed no preference for forming on the "stepped" side of the hole rather than on the opposite side—this happened in two out of five of the CX3 specimens and in three out of five of the CXSR3 test pieces. Fatigue cracks invariably nucleated at the intersection between the hole and one surface of the flat test piece.

M. W. Ozelton and T. G. Coyle (*authors' closure*)—The authors appreciate the comments of A. Alpas and C. N. Reid supporting our observations regarding the influence of the position of the pip on the fatigue life of split sleeved cold worked aluminum alloys. Though not specifically stated in our

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TABLE 4—*Mean cycles to failure (5 tests in each case). The mean life of unworked holes under these conditions is 1.82 × 10^5 cycles.*

	3 o'Clock	12 o'Clock
Cold expanded (CX)	6.72×10^5	5.37×10^5
CX and stress-relieved (CXSR)	2.34×10^5	3.00×10^5

paper, it was also observed that failure frequently initiated on the side of the hole opposite to that at which the pip was located.

We were interested in the data shown in Table 4 that indicate that a significant fatigue life reduction results from stress relief due to elevated temperature exposure. This emphasizes the need to determine the effect of typical aircraft service temperatures on the fatigue life improvement due to cold working of holes. As aircraft performance requirements continue to increase, so do the temperatures, and the need for data of this type becomes significant.