DOI: 10.1515/FAS-2017-0009
FATIGUE OF AIRCRAFT STRUCTURES (2017)
S. 109–115

THE EFFECT OF ANODIZING PROCESS PARAMETERS ON THE FATIGUE LIFE OF 2024-T-351-ALUMINIUM ALLOY

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Abstract

The effect of an anticorrosive layer on the fatigue life of 2024-T-351-aluminium alloy has been studied in the present investigation. The fatigue tests were conducted on the aluminium alloy with and without anodizing to evaluate the fatigue life. The results indicate that the fatigue life of the anodized specimens is significantly shorter than that of untreated specimens. Further, experiments were conducted to evaluate the effect of the anodizing process parameters on the fatigue life of anodized specimens. These results show that the fatigue life of anodized aluminium alloy can be improved by controlling the anodizing process parameters such as process temperature, voltage, and time of immersion.

Keywords: aluminium alloy, fatigue, corrosion, oxidation, anodizing.

1. INTRODUCTION

Aluminium and its alloys are being used successfully in a wide range of applications, from the packaging to aerospace industry. Due to their good mechanical properties and low densities, these alloys have an edge over other conventional structural materials. Hence, aluminium alloys continue to be the dominating structural materials in aircraft structural components. In most aircraft, the airframe consists of about 80% aluminium by weight [1]. In this group of materials, 2024 aluminium alloy remains an important aircraft structural material due to its extremely good damage tolerance and high resistance to fatigue crack propagation [1,2]. In 2024-T351 aluminum alloy the alloying element – copper – enhances the mechanical properties of the alloy while tending to decrease its corrosion resistance. Therefore, the surface treatment is required to protect the surface against corrosion.

Variation in atmosphere conditions together with changing climatic environments through which the aircraft commutes tend to corrode the material. The occurrence of corrosion significantly contributes to structural degradation of an aging aircraft. The effect of corrosion on the structural integrity of aging aircraft still remains underestimated, even though it has been recognized that the potential interaction of corrosion with other forms of damage such as wide spread cracking in the regions of high stress gradients can result in loss of structural integrity and may lead to serious consequences [3-4]. Present-day considerations of the corrosion induced structural degradation relate the presence of corrosion with a decrease in the load bearing capacity of the corroded structural member [4]. Bray *et al*. [5] have studied the effect of corrosion on multisite damage situations and aircraft structural integrity. Zamber and Hillberry [6] have quantified corrosion-pitting damage and related it to the decrease in fatigue life of 2024-T351 specimens corroded in the alternate immersion corrosion process. Chubb *et al*. [7] have found that prior exfoliation corrosion does not significantly affect the fatigue crack growth rate of 2024-T351 specimens. Monasalve *et al.* [8] have studied the influence of different surface treatments on the fatigue life of aeronautic aluminium alloys using S-N-P (stress, number of cycles, failure probability) curves. In order to control the effect of corrosion on aircraft structural components, the surface of the material is anodized. Through this process, a thin anodic coating is formed on the surface of the material, becoming a very good adhesive for painting. In view of the fact that fatigue resistance is a basic requirement for aircraft structural components, the objectives of the present investigation are: (i) to characterize the S–N curve of the alloy in anodized and unanodized conditions and (ii) to evaluate the effect of anodizing process parameters on the fatigue life of 2024-T-351-aluminum alloy.

2. EXPERIMENT

The material used in the investigation was 2024-T-351 aluminium alloy of composition (in wt%) Cu–3.8, Mg–1.2, Fe–0.5, Si-0.5, Mn-0.3, Zn–0.25, Cr-0.1 and Al–Balance. The alloy under investigation has been supplied in T-351 temper condition. Tensile tests were carried out on round specimens of gauge length 50 mm and diameter 12.5 mm with the help of a 200 kN Hydraulic Carl Schenck Hydroplus Universal Testing Machine (M/s Carl Schenk, West Germany) at ambient temperature ($\approx 27^{o}$C) using a cross head speed of 0.5 mm/min. The crosshead speed corresponds to nominal strain rate of 3.33×10^{-4} s^{-1}. Two tensile tests were carried out to obtain the average tensile properties of the selected steel. The fatigue tests were conducted on round notched specimens with stress concentration K=1.7. The dimensional details of the fatigue test specimen are presented in Fig.1.

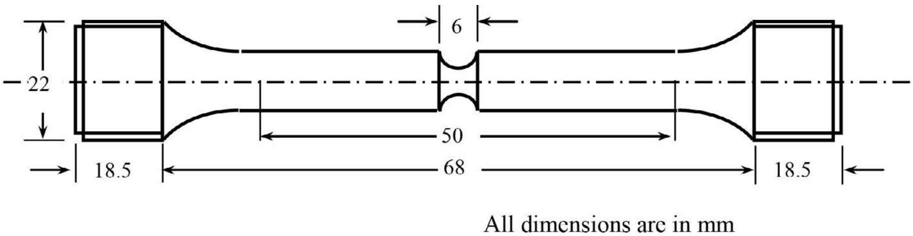

Fig. 1. Fatigue test specimen

The fatigue life characterization in terms of nominal stress (S–N curve characterization) was performed on the investigated aluminium alloy using a 200 kN Hydraulic Carl Schenck Hydroplus Universal Testing Machine (M/s Carl Schenk, West Germany). Completely reversible sinusoidal load cycles at a frequency of 30 Hz were used for all the tests. Fatigue tests were done on six batches of specimens to study the effect of pickling (cleaning) and the effect of anodizing process parameters such as temperature, voltage, and time of immersion on the fatigue life of the material, the details of which are shown in Table 1. The Batch 3 specimens were anodized with bath parameters as normal anodizing is done. In Batch 4, the temperature was raised from 40^0C to 45^0C; in Batch 5, the voltage was changed from 20V to 30V; and in Batch 6, the time was changed from 30 to 35 minutes while keeping all other parameters the same as given in Table 1.

Table. 1 ***The details of the treatment used for the fatigue test specimens***

Batch No.	Treatment	Anodizing bath compositions			
1	Untreated				
2	Pickled (Cleaned)				
3	Anodizing	Chromic acid	Temperature	Voltage	Time
		30-50 gm/ltr	40	20 V	30 min
4	Anodizing	30-50 gm/ltr	45	20 V	30 min
5	Anodizing	30-50 gm/ltr	40	30 V	30 min
6	Anodizing	30-50 gm/ltr	40	20 V	35 min

3. RESULTS AND DISCUSSION

The average tensile properties of 2024-T-351-aluminum alloy were found to be as follows: yield stress: 355 MPa, ultimate stress: 500 MPa, and elongation: 18%. The evaluated tensile properties of the material were found to be in good agreement with the results of Verma *et al*. [2] and Monasalve *et al.* [8]. Fig. 2 presents the stress vs. number of cycles to failure curve (S–N curve) for the 2024-T-351-aluminum alloy samples pertaining to Batch 3 (anodized) along with the results for the samples of Batch 2 (pickled) and untreated samples of Batch 1 (Ref. Table.1). The S–N curves obtained in this investigation are in good agreement with similar curves on 2024–T3 alloy reported in earlier investigations [2,8,9]. Figure 2 shows that for fatigue life of 1 million cycles, the untreated samples (without anodizing) withstand higher stress (245.4 MPa) than either pickled samples (217 MPa) or anodized samples do (159.4 MPa). This shows that the fatigue strength of the aluminium alloy decreases after the anodizing treatment, which ultimately decreases the fatigue life of the material under operating conditions. The present results indicate that fatigue strength is reduced by 11.57% and 35% for the pickled and anodized samples, respectively. This behavior may be attributed to the embrittlement of the material due to hydrogen absorption occurring during the anodisation process. This may be so because embrittlement cracks in anodized material may well act as initiator of fatigue cracks. These results pose a serious concern with regard to the use of anodized 2024-T-351-aluminum alloy in the design of aerospace structures.

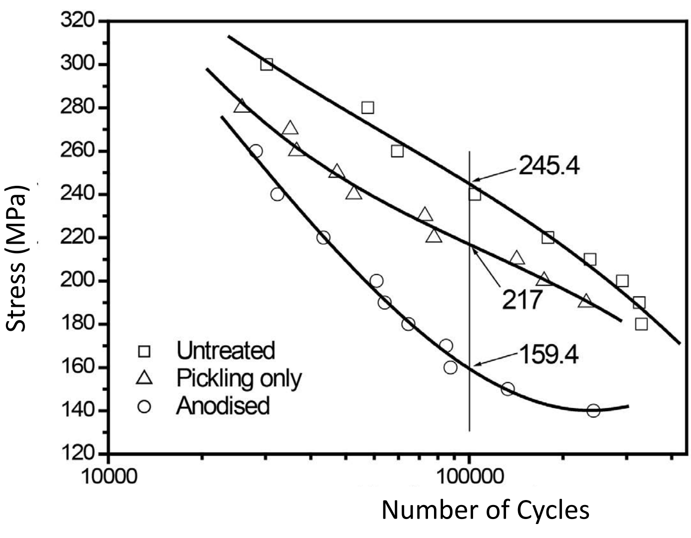

Fig. 2. S-N curves for 2024-T-351-aluminum alloy: (i) without anodizing, (ii) pickling treatment and (iii) anodized (batch 3)

In this investigation, effort has also been made to study the effect of anodizing process parameters on the fatigue strength of the alloy. In Fig.3, Fig.4 and Fig.5, the S–N curves for Batches 4, 5 and 6 samples with varied anodizing bath parameters (Table 1) are compared against the untreated samples (Batch 1). These figures indicate that the change in the anodizing bath parameters in the anodizing process affects the fatigue strength of 2024-T-351-aluminum alloy.

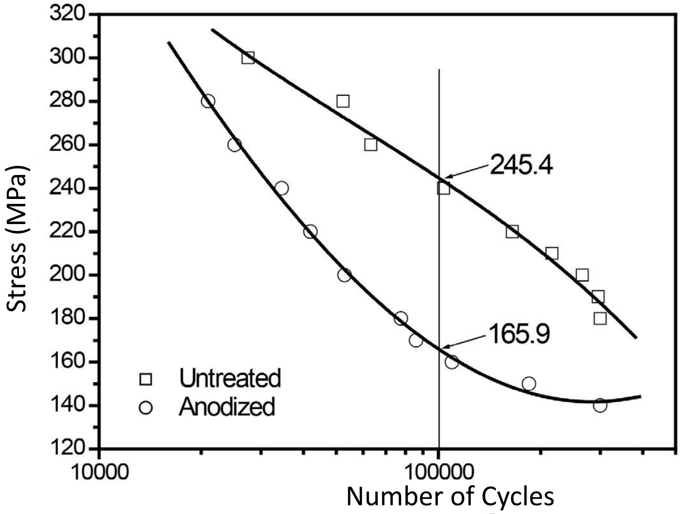

Fig. 3. S-N curves for 2024-T-351-aluminum alloy: (i) without anodizing, and (ii) anodized (batch 4)

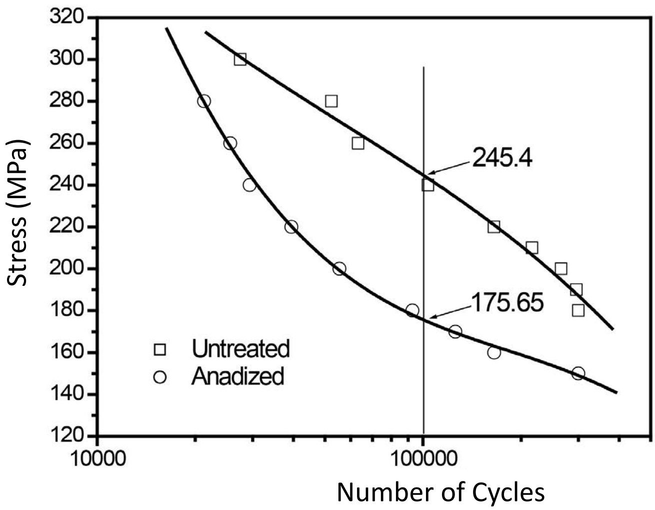

Fig. 4. S-N curves for 2024-T-351-aluminum alloy: (i) without anodizing, and (ii) anodized (batch 5)

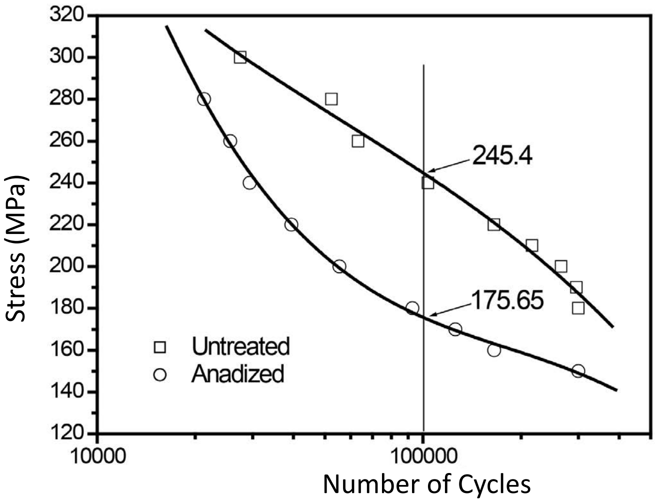

Fig. 4. S-N curves for 2024-T-351-aluminum alloy: (i) without anodizing, and (ii) anodized (batch 6)

As can be seen from Fig.3, Fig.4 and Fig.5, the reduction in the fatigue strength of the anodized alloy as compared to the untreated alloy for the fatigue life of 1 million cycles is 32.3%, 28.4% and 26.3% respectively. These values are lower than the reduction in the fatigue strength (35%) of the samples of Batch 3 with the usual anodizing process. For example, the results of the Batch 6 samples with change in time of immersion from 30 to 35 min has shown about a 9% improvement in the fatigue strength of the material. Hence, these results clearly demonstrate that the fatigue strength of 2024-T-351-aluminum alloy can be improved by changing the anodizing process parameters. The anodizing process parameters can be optimized for higher fatigue strength of the anodized alloy.

4. CONCLUSIONS

The following conclusions were drawn from the present investigation: (i) the fatigue strength of the anodized 2024-T-351-aluminum alloy for 1 million cycles is significantly less than that of the untreated alloy (without anodizing), and (ii) the fatigue strength of the anodized 2024-T-351-aluminum alloy can be enhanced by changing the anodizing bath parameters.

Acknowledgement.

The author gratefully acknowledges HAL, Bangalore for making available the material and all testing facilities.

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