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INFLUENCE OF HEAT TREATMENT CONDITIONS IN FATIGUE CRACK PROPAGATION BEHAVIOUR OF 8090 ALLOY

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ABSTRACT

The results of mechanical properties and fatigue crack propagation tests, performed with high strength 8090 Al-Li alloy, are presented in this paper. High level of strength properties is accompanied with acceptable level of fatigue threshold values, offering an alloy of superior characteristics in application, compared to other high strength aluminium alloys. The obtained results of tensile tests and fatigue crack propagation values, are discussed and compared for underage and peak-aged tempers in T-L and L-T orientation of 10 mm thick plates.

Keywords: Al-Li 8090 alloy, crack growth rate, fatigue threshold

1. INTRODUCTION

In recent years lithium-containing aluminium alloys have been introduced because of their superior mechanical properties such as combination of high stiffness and high strength with low density and potentially low unit cost. Due to their high strength-to-weight ratio lithium-containing aluminium alloys attract the attention of designers, producers and users of aircraft structures, offering reduced weight of structural parts, improved properties in strength, toughness and elasticity modulus and significant damage tolerance. In medium strength range the lithium-containing alloy of Al-Li 8090 type is considered for the replacement of traditional aluminium alloys and carbon-fibre composites.

The microstructure and mechanical properties dependence on chemical composition, purity and thermo mechanical heat treatment of these alloys is presented in references [1-7]. However, successful practical application of this alloy and service safety of machine parts, produced of this alloy, is also dependent on crack resistance properties under static and variable loads. In order the get more insight in crack behaviour of Al-Li 8090 alloy, crack growth rate da/dN vs. stress intensity factor range ΔK curves and fatigue threshold ΔK_{th} had been performed in this analysis for two heat treatment conditions: T6-PA (peak aged) and T6-UA (underage).

2. MATERIAL

Ingots of the pure Al-Li 8090 alloy, with density of 2535 kg/m^3, produced by The Institute of Nuclear Science, Vinca [8], with the actual composition given in Table 1, had been hot rolled to 10 mm thick plates and 1.6 mm thick sheets. Ingots were prepared in 16 kg heats by induction melting of pure metals and master alloy under vacuum (degassing). Lithium packed in special aluminium capsules had been added into a spinal-coated graphite crucible under high-purity argon (0.6 bar), followed by casting into a permanent steel mould. The original cast ingots had been homogenized in air in two steps: heated at 480°C for 3.7 h followed by 530°C for 3.7 h, water quenched and then the surface layer was scalped off to 38 mm thickness. After preheating at 500°C and finishing at 350°C the ingots were hot rolled into plates and sheets to final thickness.

Table 1. Chemical composition of 8090 alloy

Element	Li	Cu	Mg	Zr	Ti	Fe	Si	Al
Mass %	2.48	1.33	0.67	0.12	0.07	0.02	0.03	Bal.

The hot rolling was performed in five or seven steps with intermediate reheating between passes. Series of specimen blanks were taken from the plate in the L-T and T-L orientations. After solution heat treating, the blanks were aged to obtain two levels of strength, in underage (UA) and peak-aged (PA) conditions. The heat treatment procedures for blanks consisted of solution heat treatment at 520°C in air for 30 min, water quenching, natural ageing for a month and final artificial ageing at 168°C for 8 h (temper T6-UA) or at 190°C for 16 h (temper T6-PA). All specimen blanks were solution treated and aged between two massive copper plates heated in air for different periods of time.

3. EXPERIMENTAL PROCEDURES AND RESULTS

Following tests, required for the analysis of mechanical properties and crack behaviour, had been performed using the specimens, produced of 8090 alloy tensile tests and fatigue crack growth rates measurement.

3.1. Tensile tests

Tensile tests had been performed on the 10 mm thick specimens of square cross-section with 25 mm gauge length, machined from the plate. Uniaxial tensile properties of 8090 alloy are listed in Table 2, together with referred data [7,9,10] for other Al-Li alloys for comparison. Yield strength and ultimate tensile strength of tested alloy are of slightly lower values compared to the values of similar alloys (Table 1), and elongation is of the same level.

Table 2. Tensile properties of 8090 Al-Li alloys

Material. and heat treatment	**Yield strength, $R_{p0,2}$, MPa**		**Ultimate tensile strength, R_m, MPa**		**Elasticity modulus, E, GPa**		**Elongation A, %**	
Orientation	**L-T**	**T-L**	**L-T**	**T-L**	**L-T**	**T-L**	**L-T**	**T-L**
T6-UA	327.9	322.4	441.1	421.6	75.9	75.3	7.0	4.0
T6-PA	389.5	369.5	477.3	427.3	81.8	78.8	6.5	3.4
8090-T851	455.0		500.0		81.0		7.0	
8090-T8x	482.0		534.0		80.5		6.1	
7150-T651	404.0		480.0		76.0		6.0	

3.2. Fatigue crack growth rates measurements

Fatigue crack growth rates measurements had been performed according to ASTM E647-88, using Charpy V specimen type, taken from 10 mm thick plate. After machining, crack gauge foil RFM A-5, produced by RUMUL, had been applied on the specimen for crack growth measurement on FRACTOMAT device. Tests had been performed on fatigue device for Charpy specimens CRACKTRONIC. This device can follow crack growth using crack gauge foil or by the change of loading frequency. The dependence of crack growth rate (da/dN) versus stress intensity factor range (Δ K) for two load ratios (R = 0.1 and R = 0.5) are presented in Fig. 1.

They can be described by the equation [11]

$$\frac{da}{dN} = C_p (\Delta K)^{n_p} \tag{1}$$

in which C_p and n_p are experimentally determined parameters, according to the diagrams in Fig. 14. The stress intensity range, ΔK, is given by

$$\Delta K = P \Delta\sigma (\pi a)^{1/2} \tag{2}$$

where Δσ is the applied stress range, a is actual crack length and P describes the specimen calibration. Fatigue threshold can be also evaluated from da/dN-ΔK diagrams.

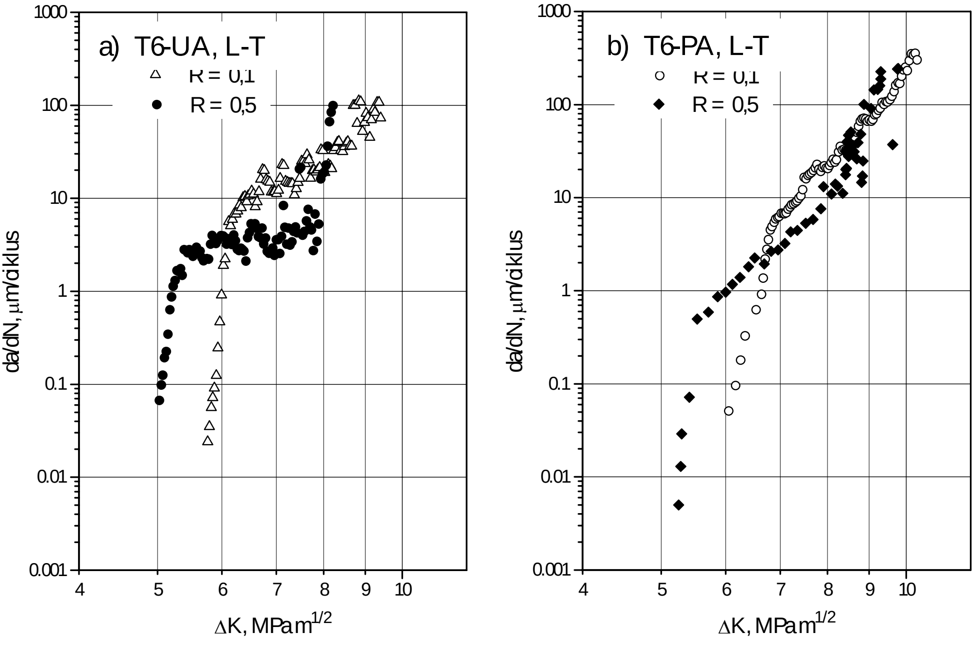

Figure 1. Diagrams of fatigue crack growth rate (da/dN) vs stress intensity factor range (Δ K) for 8090 alloy, L-T orientation, R=0.5 and R=0.1,T6-UA (a) and T6-PA (b)

It can be shown from obtained results that fatigue threshold value of stress intensity factor range ΔK_{th} for ratio R=0.1 is higher compared to the value for the ratio R=0.5, as it could be expected. The value of ΔK_{th} for 8090 alloy is higher than the values for conventional aluminum alloys, for both orientations [11]. This is expressed for low and medium crack growth rates, at which a typical shelf, characterizing stable crack growth in Al-Li alloy, can be observed. Higher crack growth rate is observed for temper PA (peak-aged temper). Some different behaviour at R=0.5 ratio could be recognized. There is no significant difference in fatigue threshold values ΔK_{th} for both tempers, and these values are higher than for conventional aluminum alloys.

Considering the alloy 2024-T351 as an excellent alloy regarding damage tolerance due to high level of crack resistance, it is possible to attribute the same to the 8090 alloy, having in mind the comparison of corresponding results. It is to be mentioned that T6 heat treatment is not specified for damage tolerance and there is some space for its improvement. These results are in agreement with published data for da/dN - ΔK curves. There is some evidence that improved crack resistance of Al-Li alloy is connected with higher value of elasticity modulus.

4. CONCLUSION

Detailed information about mechanical properties, crack resistance and fatigue behaviour of new Al-Li 8090 alloy are required for its successful application in aircraft structural parts production. Due to high level of strength, combined with acceptable level of toughness, crack resistance and fatigue properties, this alloy is superior compared to the other high strength aluminum alloys and it attracts the attention of aircraft designers and producers.

When the properties of 8090 alloy are considered, the effect of heat treatment and orientation have to be taken into account. It has been found in this investigation that peak-aged temper PA offers higher strength level compared to the underaged alloy UA, expressed by about 20% higher yield strength in L-T orientation.

In addition to the convenient mechanical properties of 8090 alloy, and, crack growth rate properties and fatigue threshold, are also at the acceptable level, offering long service life of components, produced of 8090 alloy. Anyhow, much more results regarding fatigue behaviour are required for better understanding on 8090 alloy behaviour under variable load.

All the results, obtained in this investigation, indicate possibility of further improvement in heat treatment when directed to the required characteristics for specified application. On the other hand, the effect of heat treatment and orientation has to be carefully considered in design and part production, having in mind the differences of presented characteristics values.

5. REFERENCES

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