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Influence of Cycling Impact Loads on Dynamic Crack Progression in Thin Plates under Changing Thermal

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ABSTRACT:

This article discusses the dynamic crack propagation method for two types of aluminium plates (7075 and 6061) with aspect ratios (1, 2) and plate boundary conditions that are subject to cycling thermal stresses and cycling effect loads (SFSF). Crack lengths (3, 5) mm and crack angles were measured using numerical analysis and experimental research (0o, 90o). In a thin aluminium plate with a crack, numerical analysis utilising the finite element technique programme (ANSYS-18 APDL) was used to determine the displacements caused by mechanical and thermal loads over time at the fracture tip and to compute the dynamic crack propagation through those displacements. Practically, a rig was created and manufactured to put cycling effect loads on the centre fractured plates while adjusting the temperature and monitor the dynamic crack propagation. The device was coupled to a high-resolution camera. The dynamic crack propagation was observed to rise as the crack duration rose, and to decrease as the plate's aspect ratio increased, according to the results.

KEYWORDS: stress, dynamic crack propagation, crack tip, analysis, plate.

INTRODUCTION

It is very important to study dynamic crack propagation in structures to strengthen the design against failure. Boilers, machinery, aircraft wings and vehicles all require specific cycling. The strength of the structure is reduced as the cracks spread until they are so weak that they can no longer withstand service loads [1]. Thermal stresses occur when structures expand or contract as a result of temperature changes. When the plate is heated, each component of the material experiences thermal stress in all directions. Thermal stress is caused by an increase in temperature because common structural materials expand when heated [2]. Displacement induced in a thin plate during crack tip mechanical and thermal stress analysis to determine dynamic crack propagation values. Many researchers study the forces that cause crack propagation and cracks that are affected by temperature. [3]. presented a proposed method for structural integrity analysis under thermal fatigue crack propagation. [ ]. investigates thermal stresses caused by non-uniform heat distribution in a rectangular plate. [5]. An investigation of the fracturing effects of thermal effects was presented along with the model definition. And [6]. It explains the temperature distribution and how it affects the displacement and thermal stress of a thin rectangular plate. The aim of this work is to create a model that describes the dynamic propagation of fractures in thin plates under cyclic impact loads under the influence of cyclic thermal stresses. To quantify the dispersion values with respect to time and obtain the displacements, it was designed and built using the ANSYS18-APDL package.

NUMERICAL ANALYSIS

The results of the numerical analysis were obtained using ANSYS tools. Several quantitative methods for simulating fracture mechanics have been developed, [7]. The finite-element approach used was computerized methods to predict the reactions of the real object to force, heat, vibration. These techniques were used to assess work piece, equipment, and structures behavior for different loading conditions. Entire analysis of the structure was found by simultaneous analysis of the individual elements, taking due account of their individual positions within the mesh [8]. The stresses with respect to time were analyzed to obtain the displacements by applying the cycling impact loading by impactor arm to the crack in the center of the plate under the effect of cycling thermal stresses and calculating the propagation of the crack according to time.

SELECTION OF ELEMENT

Coupled filed solid element SOLID226 had twenty nodes with a maximum of five degrees of freedom per node. The structural capabilities include elasticity, plasticity, viscoelasticity, visco-plasticity, creep, strain, tension, thermal expansion and structural-thermal capabilities, [9]. SURF152 can be used for different applications of load and surface effects. It can overlay any 3-D thermal element on an area face. Four to ten nodes defined the element, and the properties of the material. For convection or radiation effects an extra node (away from the base element) may be used, [9]. Representation three dimensions of the cracked plate as shown in figure (1).

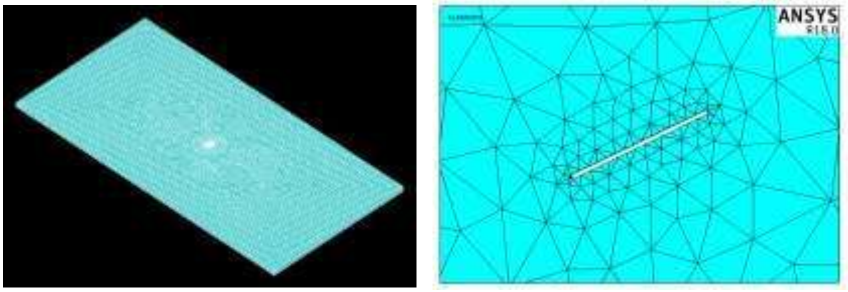

Figure 1. 3D model cracked plate

LOAD AND BOUNDARY CONDITIONS

Establish the surface area of contact between impactor and plate. The plate was defined as the contact surface while impactor defined as the target was treated as rigid with pilot node to apply the displacement. The pilot node aligned with the impactor was also used during the simulation to obtain the structural force. All contact surfaces were TARGE170 modelled for target surfaces and CONTA174 elements for contact elements. Plate mount type SFSF was used, as shown in figure (2).

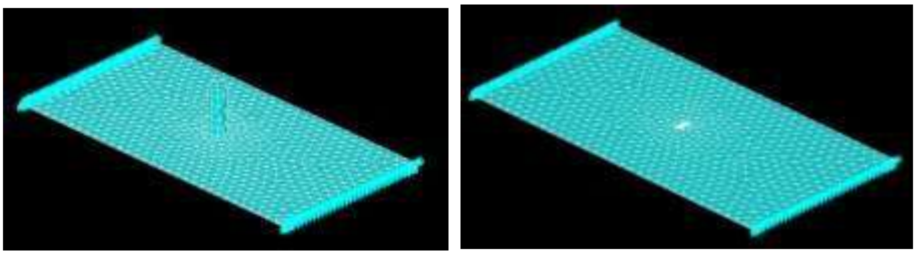

Figure 2. Load and boundary conditions of the cracked plate (SFSF)

EXPERIMENTAL WORK

Due to their excellent mechanical properties, high specific strength, high fracture resilience, high fatigue resistance, high formability, super-plasticity that meets the requirements of low structural weight, strong damage tolerance and high longevity, aluminum alloys have been extensively employed in aerospace applications and structures. Created a central crack in the plate as shown in figure (3).

Figure 3. Cracked plate (0^o, 90^o)

Aluminum (7075) alloy, uses of Al -7075 in fittings, gears and shafts for aircraft, rocket parts, valve parts control, aerospace and defense applications; bike frames, because of its high thermal conductivity, it possesses high heat dissipation capability and is also ideal for high strength and high temperature applications. Aluminum (6061) alloy, in structures 6061 aluminum alloys were used widely, most commonly in the manufacture of automotive parts. The alloy 6061 is ideal for the construction of yachts, boats, bicycle frames , aerospace, fishing reels, couplings and valves, heavy-duty systems, railway cars and pipe lines.

DESIGN AND DESICRIPTION OF THE RIG SYSTEM

A rig system was designed and built up as shown in figure (4), to achievement this work. The main purpose of rig system design to get a cycling impact loading with cycling thermal stresses effect to strike vertically at center of cracked plate's surface and measurement the values of dynamic crack propagation by camera connected with computer. It consists of electric motor, control number of strike's equipment, gearbox, velocity regulator, thermal oven, thermos couple, internal fan in oven to lowering temperatures, one step of pulleys and impactor arm, sensor to measure the number of strikes, and camera high-resolution with laptop computer. The specifications of electric motor were, power (100watt), voltage (220 volt), frequency (50Hz), and rotation velocity (780rpm) was reduced by gearbox that have a reduction ratio (1:40), the step of pulleys having (55mm) diameter of pinion pulley and (90mm) diameter of wheel pulley so as a reduction ratio (1.636), so that have a velocity for pinion pulley (19.5rpm) and suitable velocity for the wheel pulley (12rpm).

The center distance between pulleys is (220mm). A control number of strike's equipment determinates the number of strikes needed to strike a plate's surface, for this work, the number of strikes for one cycle was (80 strike/hour), used two cycles (2hours and 160 strikes). The impactor mass (1kg), impactor length is (900mm), (300mm) for it inside the oven which have a cylindrical end (R=2.5mm), The distance between end of impactor and the surface of plate was constant (80mm) and linear velocity of impactor arm is (1.25m/s) moves vertically to strike the cracked plate's surface. Base for fixing the plate inside the oven, the type of fixing of the plate can be controlled manually. There is a small lever fixed on the perimeter of the large pulley and there is a small base attached to the impactor arm where the lever raises the base through the rotation of the pulley leading to the rise of the impactor arm and then its fall free fall on the plate and so the process is repeated according to the number of strikes required. Plates were hold through (simply-simply with free at the other edges).

Figure 4. Rig system

PROCEDURE OF THE WORK

Dimensions of crack (length: 3mm & 5mm, width: 0.1mm, and depth:2mm). The cracked plate was placed in the middle of the convection oven, where it was exposed to normal heat from the top and bottom of the convection oven via a heater. The plate was vertically impacted by the impactor in the middle of the plate through a variety of cycles. By regulating equipment, the number of the cycles was controlled. Worked to raise the plate temperature inside the oven from room temperature 25c^o to 200c^o with an approximate 15-minute increase in time by monitoring the oven and 20 strikes via the number control system, then the temperature was set at 200c^o for 30 minutes with 40 strikes and then the temperature was reduced by 20 strikes at room temperature 25c^o by 15 minutes, so that one cycle of 80 strikes lasts 60 minutes and repeated the second cycle process so that the total time was 120 minutes and 160 strikes. The crack propagation determined by camera was connected to the laptop computer and the propagation was calculated with time under the influence of temperature with cycling impact loading for various plate aluminum alloys (7075, 6061), with variable crack lengths (3,5) mm with specific aspect ratio (1, 2) and crack angles (0^o, 90^o). This work employed forms of boundary condition free-free, with the other edges plate simply supported (SFSF) as shown in figure (5).

Figure 5. SFSF-boundary condition

NUMERICAL ANALYSIS RESULTS AND DISCUSSION

Crack lengths and crack angles effect on dynamic crack propagation, the effect of crack length and crack direction on dynamic crack propagation, crack lengths (3, 5) mm, crack angles (0^o, 90^o) were illustrated in figure (6) to figure (13). The displacement in the plate was directed proportionally with the stress applied, which means the increase in the crack length which leads to an increase in the stress values and thus to an increase in the crack propagation, therefore note from the figures that the crack growth propagation for the length of 5mm is higher than the crack growth of 3mm under the same conditions. The crack's mechanical behavior shows a large growth of the crack at 0^o angle where the direction of the crack length is toward the x-axis, and the effect of the displacements resulting from the loading and temperature effect of the cycling impact is applied vertically to the crack length. The crack growth starts to decrease at angle 90^o, where the length of the crack is perpendicular to the x-axis and the direction of the displacement applied is parallel to the length of the crack. The crack 's mechanical behavior shows the gradual growth and spread of the crack over time and the increase in the stresses caused by the crack, leading to a clear increase in the crack's development, particularly after 2700 seconds, where it contributes to a growth acceleration, to achieve its limit of 7200 seconds. That there are other limiting values because strain hardening will influence the performance, so that the rate of-curve slope will be small until almost 2700 seconds, then the rate of curve slope will rise high. It can be seen that the dynamic crack propagation rate in Al-6061 is very high as compared to Al-7075, it is shown that the dynamic crack propagation depends on the stiffness of the materials. Aspect ratios effect on dynamic crack propagation, via the results as shown in figure (6) to figure (13). It was noted that the crack growth values for aspect ratio 1 are high compared to those aspect ratio values of 2 for the same conditions. The propagation of crack growth varies from material to material where the propagation of crack growth in ductile materials such as aluminum 6061 is greater than that for hard material such as aluminum 7075, as the propagation of crack growth depends on the elasticity modulus and material density.

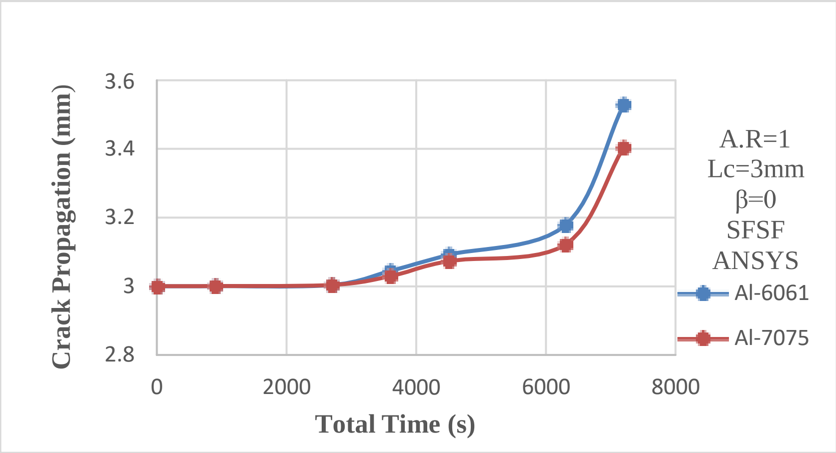

Figure 6. Crack propagation with time (A.R=1, β=0, Lc=3mm)

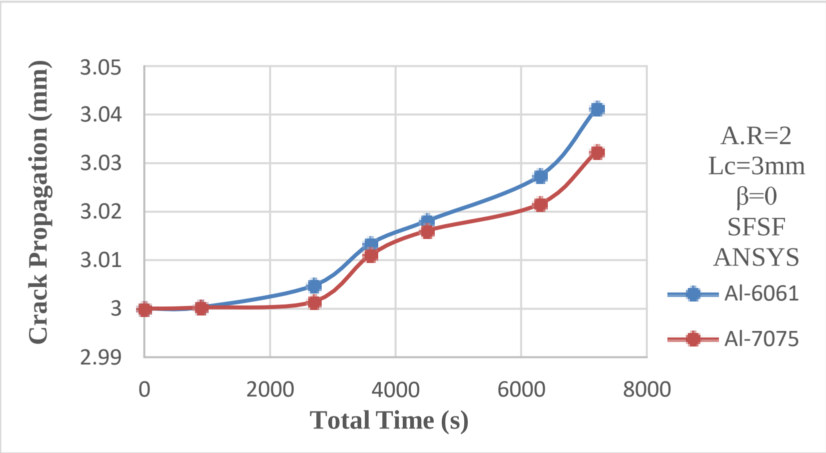

Figure 7. Crack propagation with time (A.R=2, β=0, Lc=3mm)

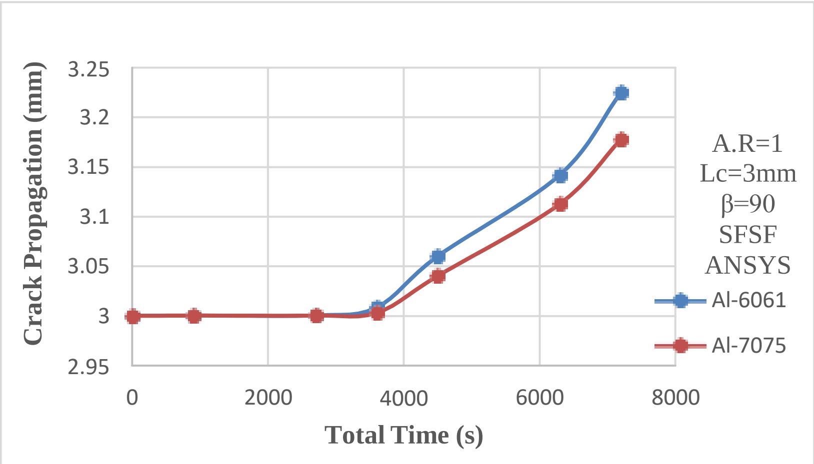

Figure 8. Crack propagation with time (A.R=1, β=90, Lc=3mm)

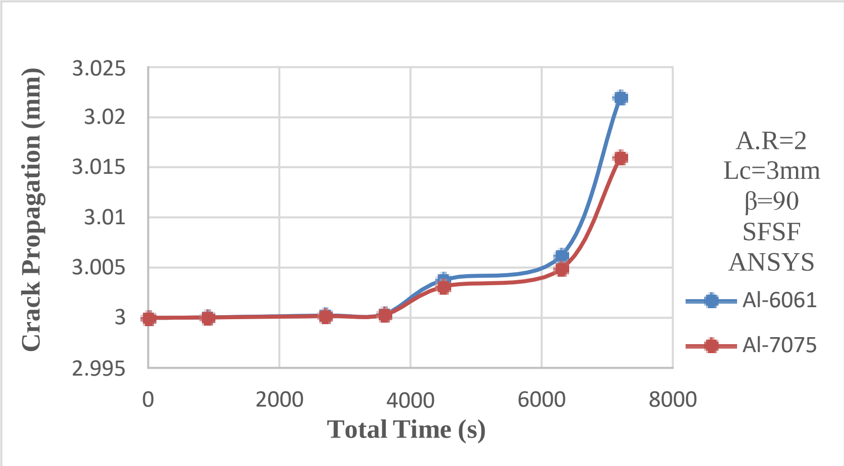

Figure 9. Crack propagation with time (A.R=2, β=90, Lc=3mm)

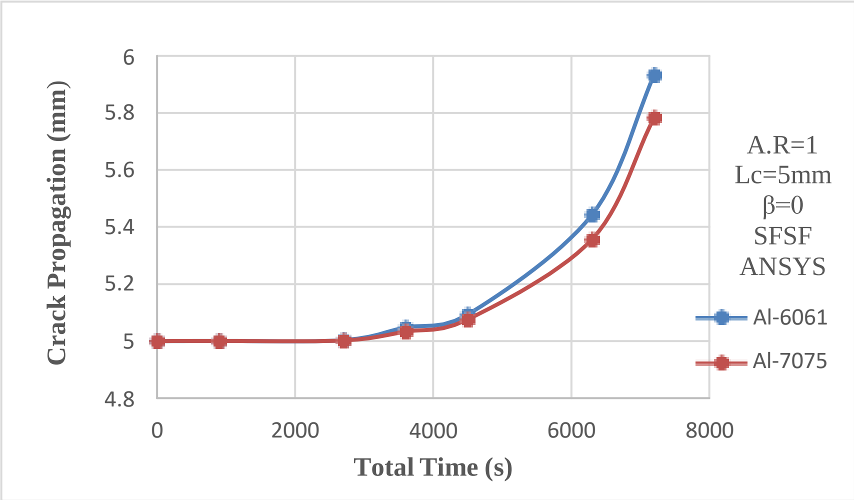

Figure 10. Crack propagation with time (A.R=1, β=0, Lc=5mm)

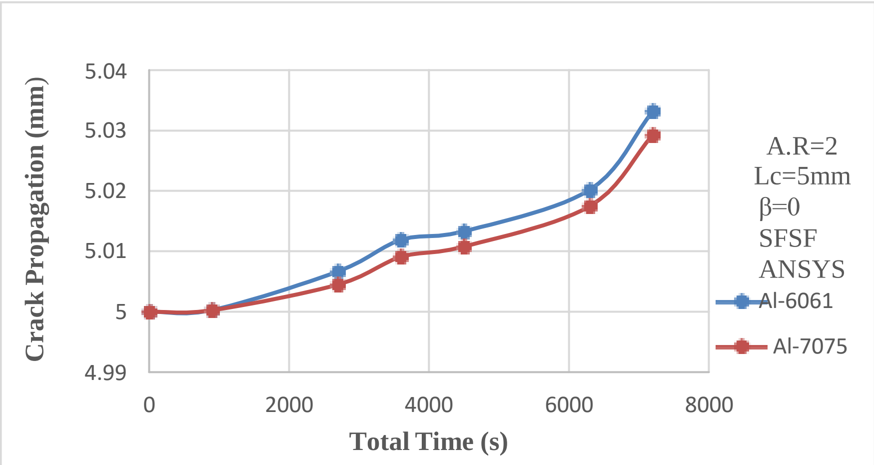

Figure 11. Crack propagation with time (A.R=2, β=0, Lc=5mm)

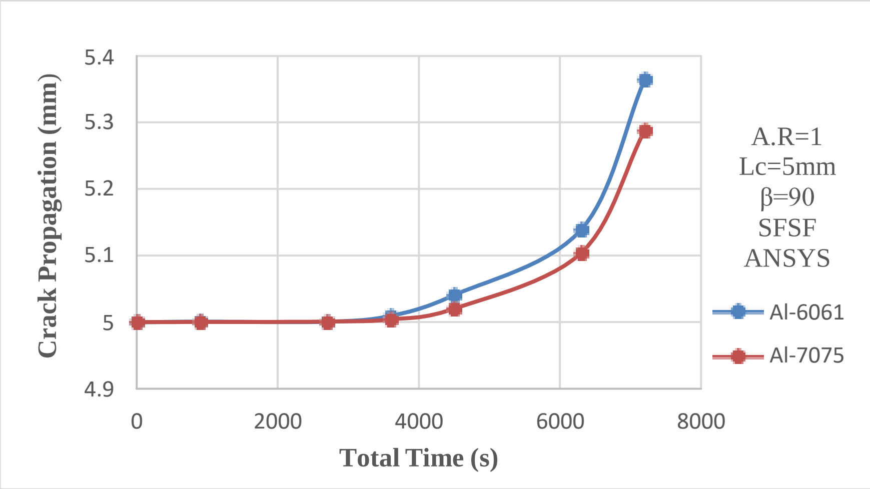

Figure 12. Crack propagation with time (A.R=1, β=90, Lc=5mm)

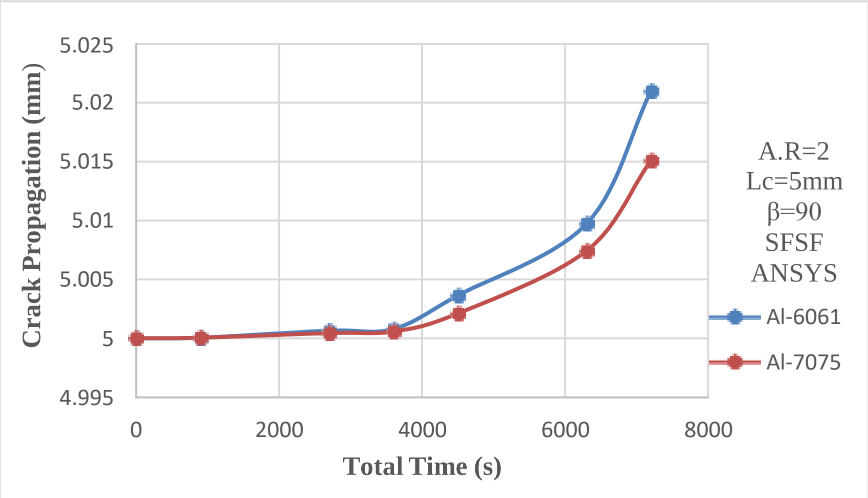

Figure 13. Crack propagation with time (A.R=2, β=90, Lc=5mm)

EXPERIMENTAL WORK RESULTS AND DISCUSSION

Crack lengths and crack angles effect on dynamic crack propagation, the effect of experimental crack lengths and crack angles on dynamic crack propagation under the number of impactor strikes (cycling impact loading) and cycling thermal stresses with a total period of 7200 seconds is demonstrated in figure (14) to figure (21). The average percentage of error (5.9%) between numerical analysis and experimental research when comparing the results. Aspect ratios effect on dynamic crack propagation, the effect of experimental aspect ratios on dynamic crack propagation under the number of impactor strikes (cycling impact loading) and cycling thermal stresses with a total period of 7200 seconds is demonstrated in figure (14) to figure (21).

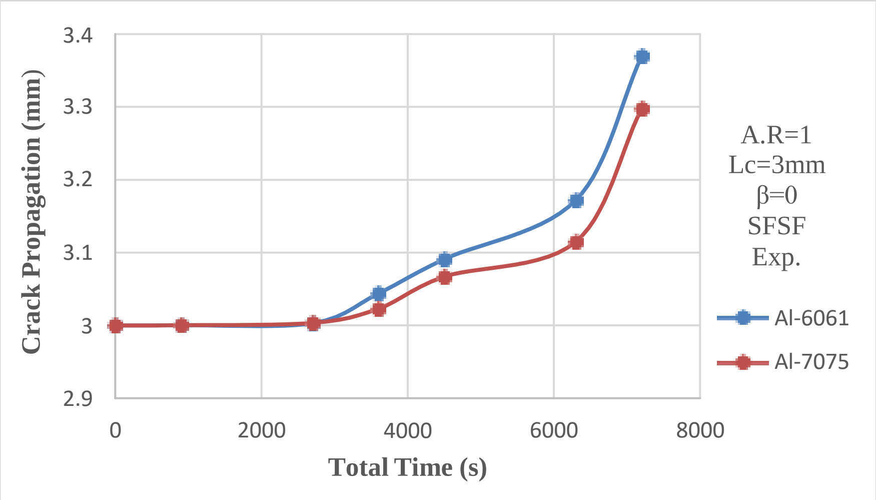

Figure 14. Crack propagation with time (A.R=1, β=0, Lc=3mm)

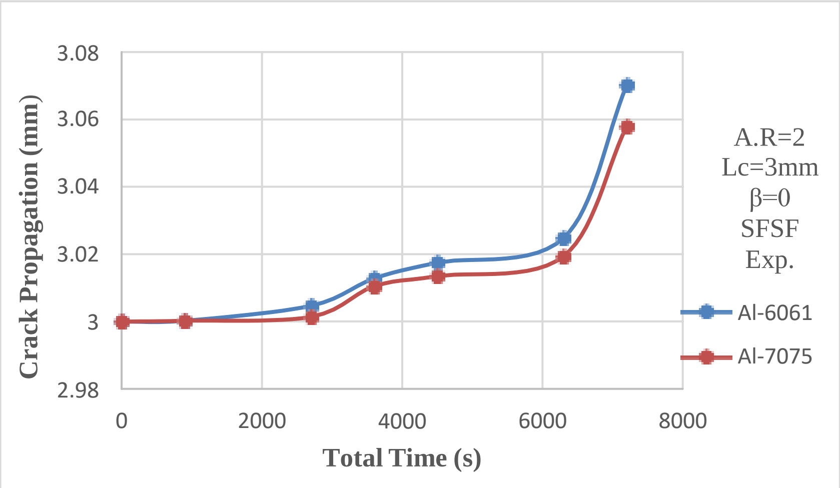

Figure 15. Crack propagation with time (A.R=2, β=0, Lc=3mm)

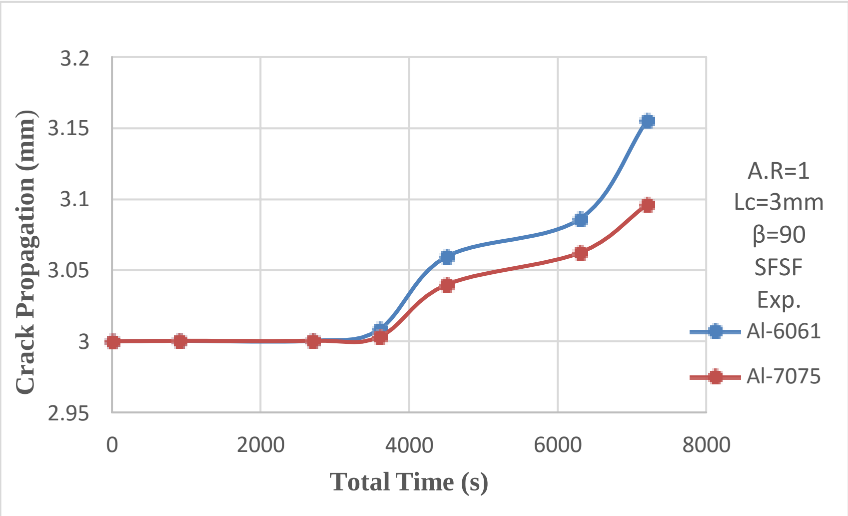

Figure 16. Crack propagation with time (A.R=1, β=90, Lc=3mm)

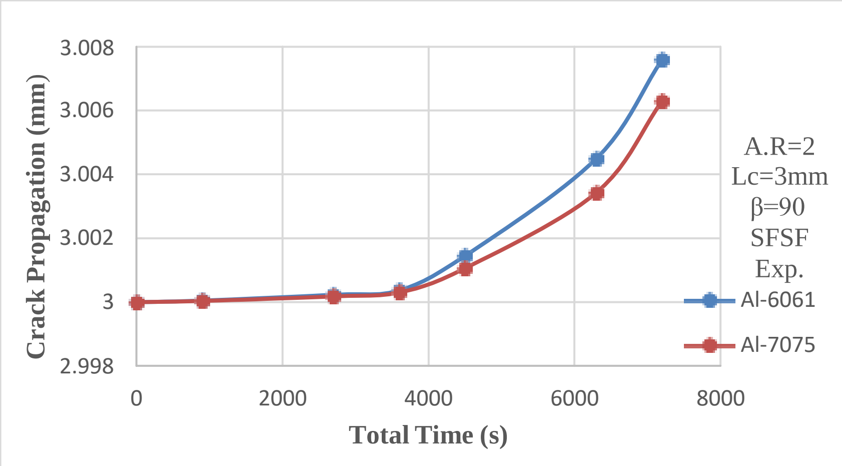

Figure 17. Crack propagation with time (A.R=2, β=90, Lc=3mm)

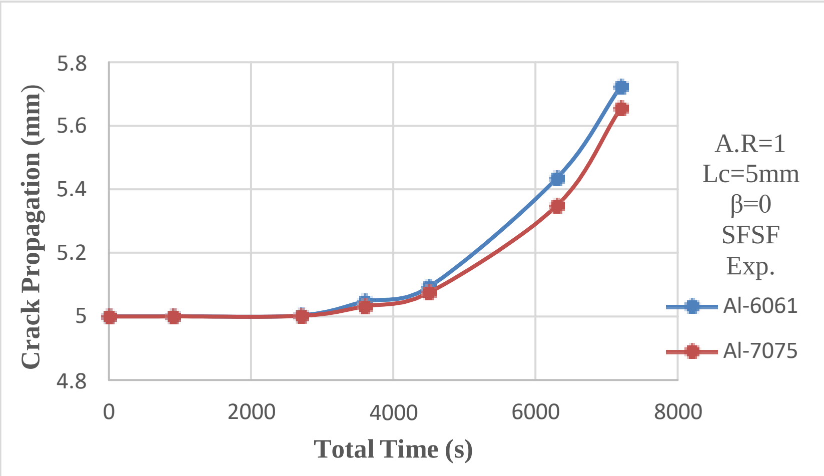

Figure 18. Crack propagation with time (A.R=1, β=0, Lc=5mm)

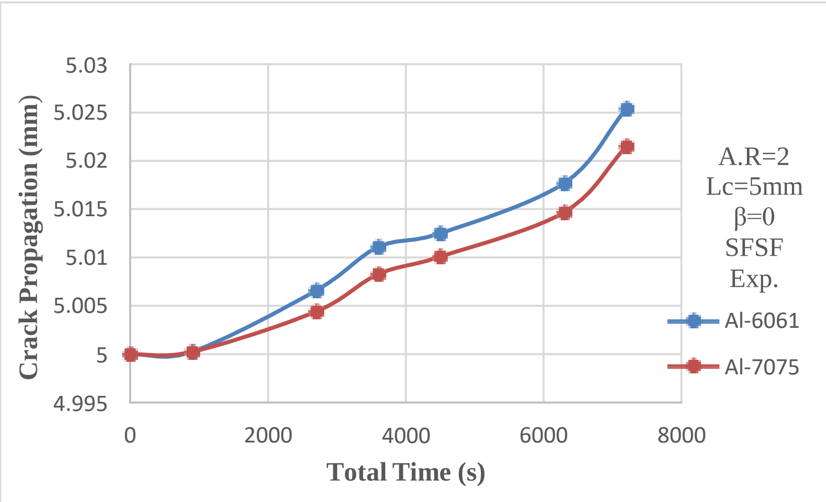

Figure 19. Crack propagation with time (A.R=2, β=0, Lc=5mm)

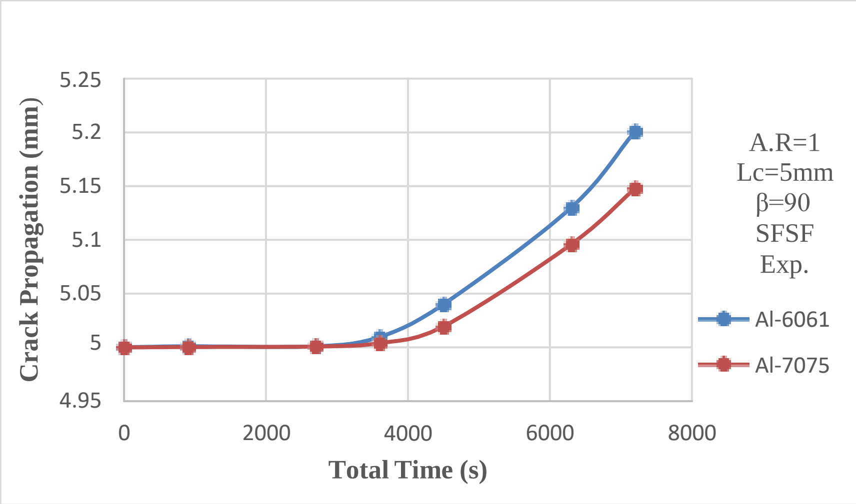

Figure 20. Crack propagation with time (A.R=1, β=90, Lc=5mm)

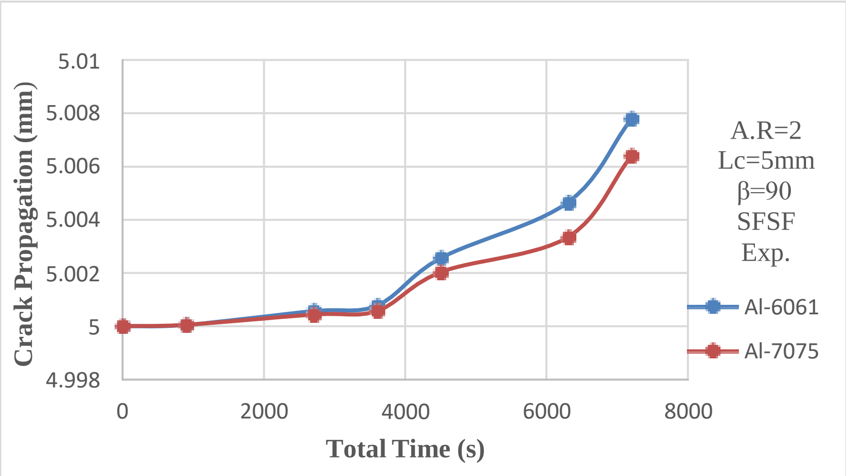

Figure 21. Crack propagation with time (A.R=2, β=90, Lc=5mm)

CONCLUSIONS

At the same angle and identical boundary conditions, it was found that the crack growth propagation rate with a length of 3 mm was lower than the rate of crack propagation for the length of 5 mm. The dynamic crack propagation rate readings at angle 00 (the crack's length in the x-direction) are higher than the values at angle 90o (the crack length vertically on the x-direction). It was discovered that the bigger the aspect ratio of the plate, the lower the stresses would have been, and as a result, the rate of fracture growth would have been slower. As a result, the smaller the aspect ratio, the greater the rate of crack propagation. At the same fracture length and conditions, it was discovered that the Al-6061 alloy's crack growth rate was higher than that of the Al-7075 alloy. It was observed that an increase in the strikes causes the stresses acting on the cracked plate to increase, which in turn causes an increase in the values of the dynamic crack propagation.

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