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Fretting Fatigue behavior of Bolted Single Lap Joints of Aluminum alloys

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***Abstract*—**In this paper, the effect of bolt clamping force on the fatigue behavior of bolted single lap joints of aluminum alloy 2024-T3 have been studied using numerical finite element method. To do so, a three dimensional model according to the bolted single lap joint has been created and numerical analysis has been carried out using finite element based package. Then the stress distribution and also the slip amplitudes have been calculated in the critical regions and the outcome have been compared with the available experimental fatigue tests results. The numerical results show that in low applied clamping force, the fatigue failure of the specimens occur around the stress concentration location (the bolted hole edge) due to the tensile stresses and thus fatigue crack propagation, but with increase of the clamping force, the fatigue life increases and the cracks nucleate and propagate far from the hole edge because of fretting fatigue. In other words, with the further increase of clamping force value of the joint, the fatigue life reduces due to occurrence of the fretting fatigue in the critical location where the slip amplitude is within its critical occurs earlier.

***Keywords*—**fretting fatigue, bolted single lap joint, torque tightening, finite element method.

I. Introduction

WITH the increasing advancement in the science and technology, the need for optimum designing of the pieces and mechanical parts is felt more and more. Considering these points, the methods for joining the pieces and parts in industry enjoys a high importance because of regards in safety, the ability to tolerate load, simplicity of application and production cost and among the joints, the bolted joints are of separable joints highly applied in different industries and these joints are mostly preferred in aerospace industry in comparison to other joints because of high resistance against fatigue and their reassemble capabilities. Therefore a great deal of study has been done about these joints and the effective parameters on the mechanical behavior have been determined [1-3]. In bolted joints, making of hole in joining pieces to assemble nut and bolt causes the creation of a site tension concentration around the ho , reduction of the area tolerating force and the development of the surface weakness. In these kinds of joints, at the time of assembling of the parts, a clamping load force can be developed in the bolt by applying torque on the bolt, and the existence of this clamping load, depending on the applied torque, can cause the transference of the part of the tensile load to between the plates instead of the shank of the bolt through the friction force and as a result not a high pressure is directed to the hole area. But the transference of the part of the force by the friction of the plate in dynamic loading leads to fretting fatigue in the piece [1,4].

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As a result, created clamping force in the bolted joint will be effective on the static and dynamic performance of the joint [5,6] that the amount of the clamping force is very important specially in cyclic loading and leads to increasing of fatigue life of joint by introducing compressive stress around the hole [7].

In this study, first t0020bvche three dimensional model has been experimented (single lap joint) and the bolted joint has been made in several stages. Then by applying the torques from0 to 8 N.m (according to experimental fatigue tests of specimens, see Fig. 1[1]) to bolted joints, the effect of the values of these torques on the effective parameters on fretting fatigue was studied. For this purpose, the finite element software ANSYS has been used and the fatigue test conditions with different values of the joint initial torque and outer axial force on the plate have been simulated and the obtained results have been compared with the experimental tests.

II. Modeling And Numerical Analysis

In numerical analysis, a model of the Fig. 2 has been used. The configuration and dimensions of the joint are similar with reference [1] as shown in Fig1. The material behavior in models have been taken into account in elastic and plastic form with kinematic hardening to make the analyses more and more close to reality. The elasticity modulus and Poisson's ratio are defined E= 71.5 GPa and υ=0.33 respectively. Since the steel bolt stays under clamping load force and axial loading in elastic region, its behavior has been considered in elastic manner with ratios of E=207 GPa and υ=0.3 respectively. In order to mesh the plates and bolts, the three dimensional element of Solid 95 has been used [8].

In the first stage of the solution, the uniform temperature reduction to the shank of the bolt has been used for modeling of applying the assembly torque to bolted joints to get an axial force equivalent to the joint assembly torque in the shank of the bolt. In the next stage by exerting the tensile load to the end of the plate, the fatigue load has been modeled and at the end by omitting the applied tensile load applied in the stage of the loading, the cycle of the fatigue load has been simulated.

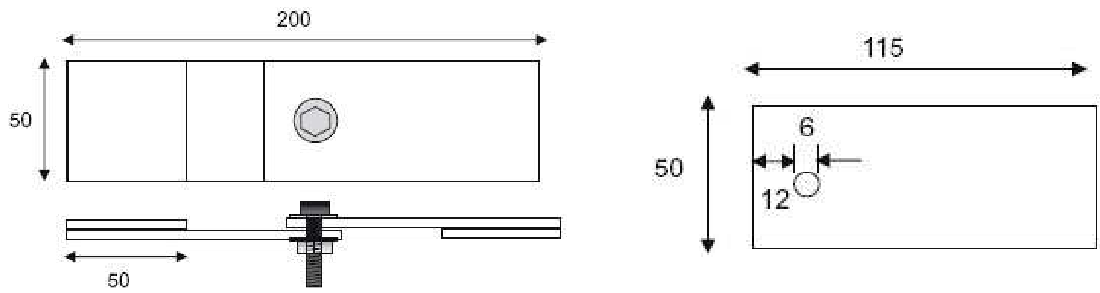

Fig. 1 Dimensions of the single lap joint (mm)

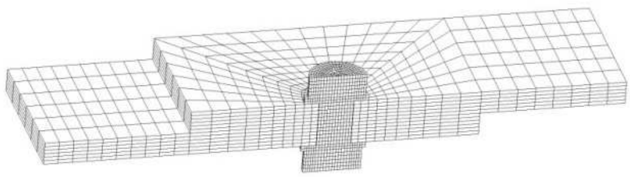

Fig. 2 Finite element model of single lap joint

III. Discussion And Conclusion

Fig .3 shows the results of experimental fatigue tests and the variation of the fatigue life in different clamping force and load amplitudes. There are three different failure modes shown in this figure.

In low and middle values of applied torque in Fig3, with the increase in clamping load force of the bolt in the sample in a certain force cycle exerted on the joints, the fatigue life of the joint increases but in high amounts of torque with the increase of in clamping force of the bolt , the joint fatigue life decreases.

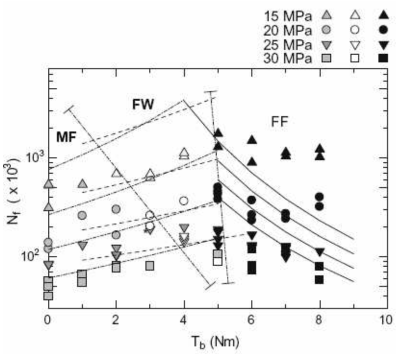

Figure 3. Change in fatigue life N_f with tightening torque T_b

The development and extension location of the cracks of the fatigue in the sample vary depending on the extent of the clamping load force and tensile load extent exerted to the joints. In a fixed cyclic tensile for all the samples with the low clamping load, the development of the cracks occurs from the edge of the middle hole (Fig. 4), but in samples with a high clamping load force, the fatigue cracks are in a quite farther distance from the hole in the complete region due to the fretting phenomenon (Fig. 5, 6). With regard to fatigue figure, for the joints with low clamping load force and clearance fit joints, it is observed that bolting, even with low extent of hardening torque, improves the joint fatigue life.

As a result, hardening torque and clamping load must be used in bolted joints. From the other side, the findings of the finite element analysis shows that in low torque values, the maximum amount of the axial tension occurs in the edge of the hole and this shows the development and growth location of the crack. While in samples enjoying higher amounts of bolted joint assembly torque, the development and growth location of the crack can be obtained by measuring the slippage in the dynamic loading length with regard to fretting phenomenon (see Fig 5, 6). Then in places that the slippage is within certain interval of 5-50 microns [9], the possibility of occurrence of the cracks is high.

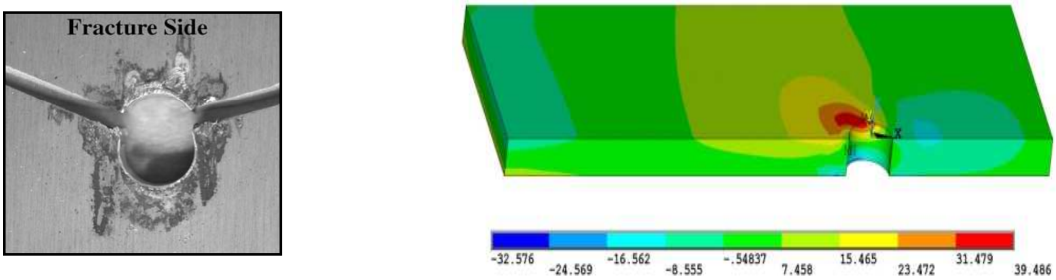

Fig. 4 The broken samples and axial stress in a specimen with low value of torque

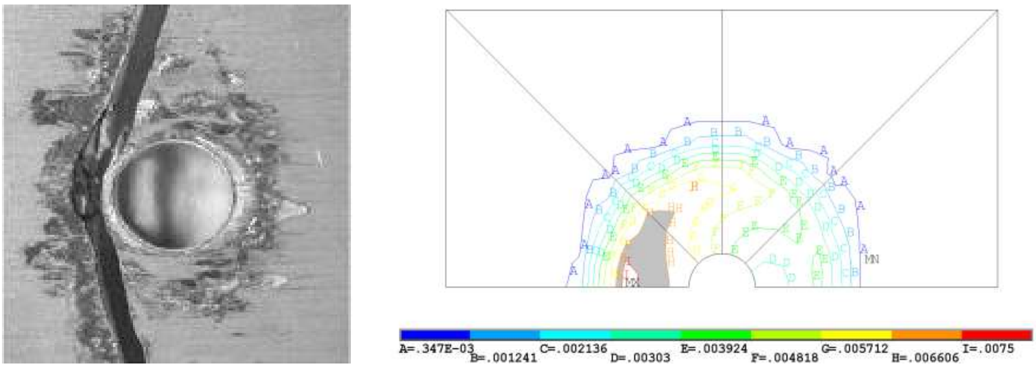

Fig. 5 The broken specimen and the slip extent in samples with middle torque value

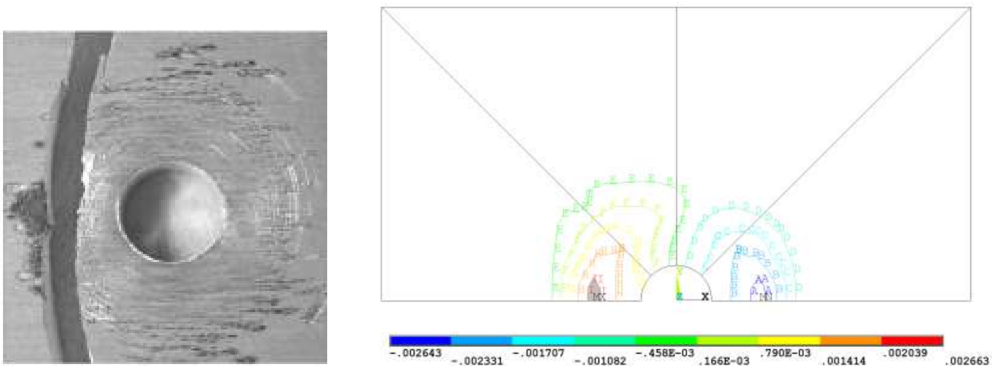

Fig. 6 The broken specimen and the slip extent in samples with high torque value

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