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SIMULATION OF FATIGUE CRACK GROWTH IN A2024-T351 T-WELDED JOINT

SIMULACIJA RASTA ZAMORNE PRSLINE U A2024-T351 T ZAVARENOM SPOJU

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Keywords
- friction stir welding
- aluminium alloys
- fatigue crack growth
- extended finite element method
- fatigue life

Ključne reči
- zavarivanje trenjem sa mešanjem
- legure aluminijuma
- rast zamorne prsline
- proširena metoda konačnih elemenata
- vek zamora

Abstract

Fatigue crack growth in friction stir welded T joints under three point bending is simulated numerically using the Extended Finite Element Method (XFEM). Three point bending fatigue load stress is applied at the centre of the plate opposite to the initial crack, with a ratio of stress intensity R = 0 and maximum stress $\sigma = 10$ MPa. The material properties of all welded regions in the joint, made of aluminium alloy A2024-T351, are adopted from available experiments. All fatigue crack propagation and growth including crack front coordinates (x, y, z) and stress intensity factors (K_I, K_{II}, K_{III} and K_{ef}) are extracted from the analysis results.

Izvod

Opisana je numericka simulacija rasta prsline u T spoju od aluminijumske legure A2024-T351, koji je zavaren trenjem mešanjem, pri savijanju u tri tačke, primenom metode konačnih elemenata (XFEM). Zamorno opterećenje pri savijanju u tri tačke deluje u centru ploče na suprotnoj strani od početne prsline, sa odnosom intenziteta napona R = 0 i maksimalnim naponom $\sigma = 10$ MPa. Osobine materijala u svim oblastima zavarenog spoja su usvojene na osnovu dostupnih eksperimenata. Svi parametri napredovanja i rasta zamorne prsline, uključujući i koordinate fronta prsline (x, y, z) i faktore intenziteta napona (K_I, K_{II}, K_{III} i K_{ef}) su dobijeni na osnovu rezultata analize.

INTRODUCTION

The use of friction stir welding process (FSW) has been increased significantly in recent decades due to its versatility and simplicity. Application of FSW process in the welding industry is still developing since it provides higher formability when compared to fusion welding. Also, friction stir welding produces welded joints with fewer defects and thus of high quality, especially with Al alloys, as 2024-T351, being otherwise practically impossible to weld. The achievements of friction stir welding contributed to the study of mechanisms and useful parameters to alter material characteristics using the friction stir processing, including T joint of 2024-T351 aluminium alloy, /1/. Anyhow, there is still much to be done to better understand fatigue crack growth in T joints. The main objective of this work is to study the effects of loading on crack propagation in different areas of FSW in the case of a 2024-T351 aluminium alloy using finite element (FE) analysis. In the numerical approach, the stress intensity factor is determined by using ABAQUS and MORFEO software based on the extended finite element method, as already used in the case of butt joints, /2, 3/, and T joint, /4/.

The extended finite element method (XFEM) is developed to overcome difficulties caused by attempts to solve problems with localized features by using mesh refinement, /5/. The most important advantage of XFEM is that the finite element mesh needs not to be updated to follow crack path. Morfeo/Crack has implemented the XFEM method available in Abaqus, making it capable of performing crack propagation simulations in complex geometries. Morfeo communicates with Abaqus in every propagation step and in between them, then reads the Abaqus solution, recovers improved XFEM solution in a small area around the crack and computes the SIFs. In order to verify this procedure, results from a 3D simulation are used and compared with experiments carried out on standard Charpy specimen /6/, pressure vessels /7, 8/, and thin-walled structures, /9/.

From the point of view of material behaviour, both FEM and XFEM simulation requires basic tensile properties, elastic and elasto-plastic, as well as parameters of the fatigue crack growth rate, e.g. *C* and *m* in the Paris law. These are all well known for the base metal (AA2024-T351), /10/, but there are very few data about weldments, i.e. material properties of different regions in welded joints.

MATERIAL PROPERTIES - AA 2024-T351

Tensile elastic-plastic properties of AA 2024-T351 weldments are well known in all regions of the welded joint (Fig. 1). Anyhow, for the material coefficients in the Paris law (C and m) we still rely on base metal data, taken from /8/, having the same value for all zones, $C = 2.02345\cdot10^{-10}$ cycles^{-1}, $m = 2.94$.

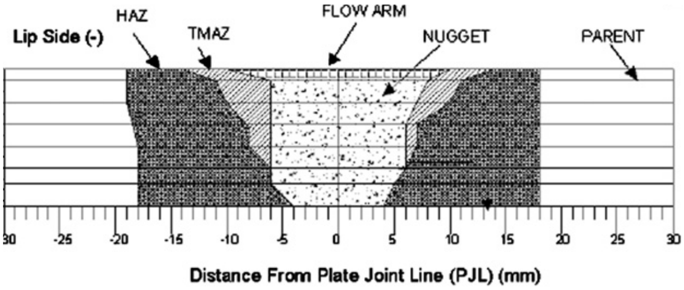


Figure 1. Characteristic regions in friction stir welded joint of AA 2024-T351, /10/.

Numerical model of Aluminium 2024-T351 T-joint

In order to make the numerical model of a cracked welded joint following has to be done: Create 3D model, i.e. define shape and dimensions, Fig. 2; Define materials, i.e. mechanical properties for all different zones in welded joint; Introduce the initial crack within the structure, including its shape and location; Introduce the loading: intensity, type and location within the structure; Define the boundary conditions; Generate final mesh, refined around the initial crack and in regions where the crack is expected to grow, Fig. 3.

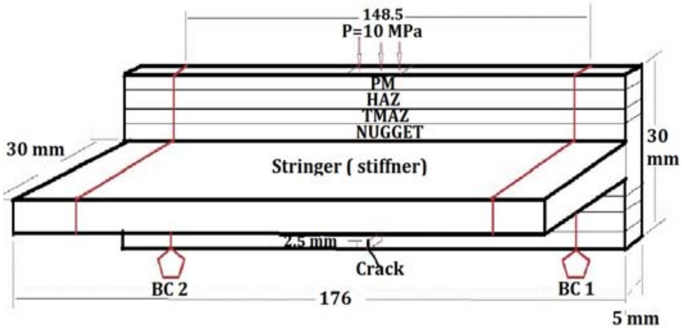


Figure.2. Three point bending specimen FS welded T joint.

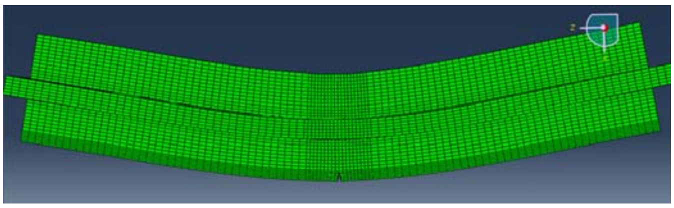


Figure 3. Finite element mesh.

RESULTS AND DISCUSSION

In this section, all simulation analyses are performed using ABAQUS/Morfeo software. Results for the stress intensity factors at the crack tip are given in Table 1 for 41 crack growth steps (each increment approximately 1 mm), together with the crack growth rate, *da/dN*, in mm/cycle.

Table 1. Numerical data: SIF and *da/dN* vs. crack length.

Step No.	Crack length, mm	SIF, K_I MPa√mm	Number of cycles, N	Crack growth rate, *da/dN* (mm/cycle)
1	2.5	197.939	0	0.001142
2	3.4986	224.59	738.813	0.001656
3	4.3297	248.385	1264.666	0.002227
4	5.32859	269.158	1666.107	0.002820
5	6.33482	285.361	1992.416	0.003349
6	7.33147	297.894	2273.044	0.003800
7	8.36644	308.751	2522.826	0.004222
8	9.32224	316.098	2751.53	0.004524
9	10.36135	309.444	2979.453	0.004250
10	11.31191	308.735	3215.339	0.004221
11	12.23196	292.802	3471.953	0.003612
12	13.20254	255.786	3815.994	0.002428
13	14.226001	213.736	4370.564	0.001431
14	15.227761	172.141	5378.604	0.000757
15	16.228301	162.915	6812.964	0.000644
16	17.228501	152.244	8534.034	0.000528
17	18.228541	142.865	10620.38	0.000438
18	19.228541	137.803	13028.75	0.000394
19	20.228441	132.325	15725.29	0.000349
20	21.228341	127.051	18763.88	0.000310
21	22.228341	122.602	22161.86	0.000279
22	23.228141	120.355	25837.7	0.000264
23	24.228041	117.023	29775.88	0.000243
24	25.227941	113.935	34044.13	0.000225
25	26.227841	111.259	38640.55	0.000210
26	27.227841	108.53	43577.61	0.000195
27	28.227941	106.021	48876.95	0.000182
28	29.227941	103.839	54531.29	0.000171
29	30.227941	101.954	60519.68	0.000162
30	31.227941	100.058	66843.87	0.000153
31	32.227941	98.0711	73539.96	0.000144
32	33.228041	96.2524	80628.41	0.000137
33	34.228041	94.6008	88101.99	0.000130
34	35.228041	93.0888	95951.59	0.000124
35	36.228041	91.6158	104180	0.000118
36	37.228041	90.4451	112763.6	0.000114
37	38.228041	89.4174	121658.9	0.000110
38	39.228041	88.638	130821.5	0.000107
39	40.228041	88.8284	140072.8	0.000108
40	41.227941	89.4217	149205.6	0.000110
41	42.227841	93.4183	157703.5	0.000125

It is clear that from step 1-8 that the stress intensity factor increases rapidly, until it reaches the stiffener (stringer), when its values start to decrease. The same holds for the crack growth rate: it starts to decrease after step 8, indicating a redistributed load to larger areas due to the shape of welded joint. All this may lead to an increase in structural life of the welded structure.

Crack growth rate vs. stress intensity factor in Fig. 4, whereas the crack opening and von Mises stress distribution at the crack tip are shown in Fig. 5. Figure 6 shows different crack propagation and von Mises distribution in steps 10, 20, 30 and 40. Generally speaking, the higher the magnitude of the stress, the smaller the number of cycles. In any case, this structure will maintain its integrity under given amplitude load since the stress intensity factors are much smaller than typical values of the fracture toughness of this alloy.

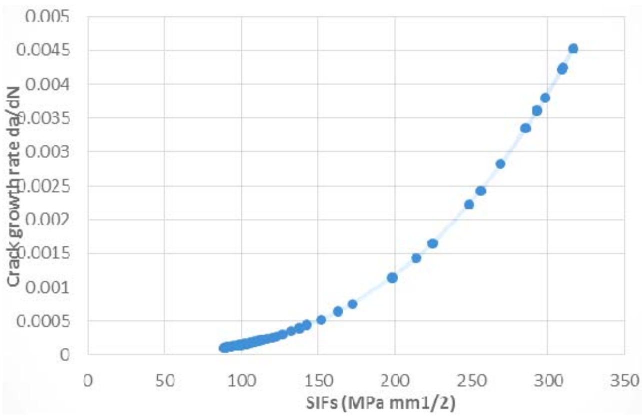


Figure 4. Stress intensity factor vs. crack growth rate

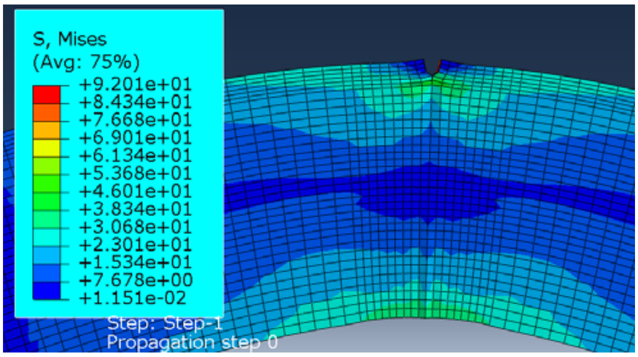
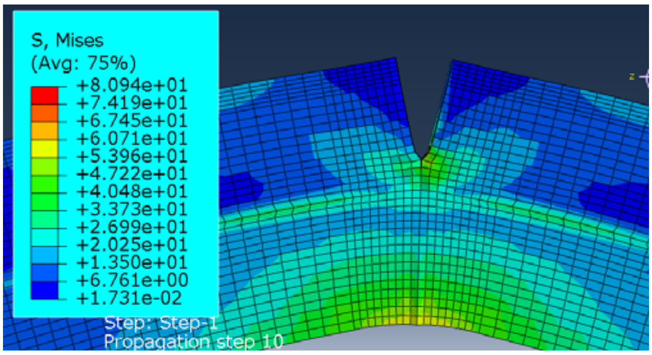
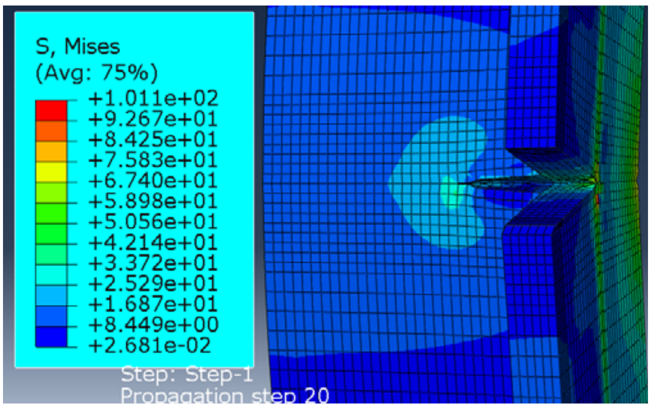


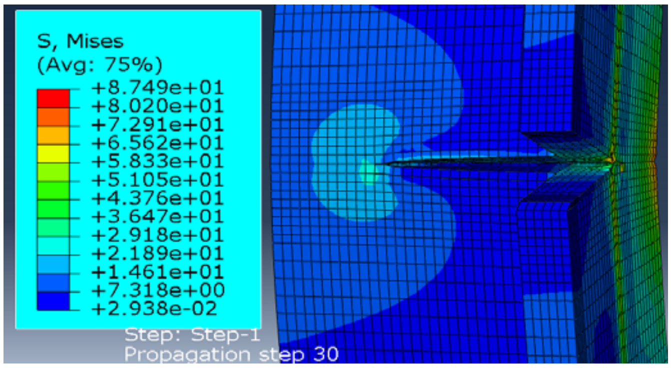
Figure 5. Initial state, Step 0 - crack opening and von Mises stress at crack tip



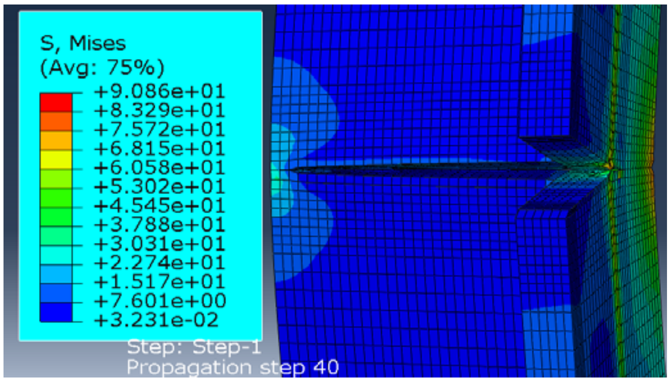
a)



b)



c)



d)

Figure 6. Crack length after: a) 10 steps, b) 20 steps, c) 30 steps, d) 40 steps.

CONCLUSIONS

Based on presented results, one can conclude that the finite element method, in combination with the XFEM, can be successfully used to simulate fatigue crack growth in a complex 3D geometry, such as T welded joint. It is indeed a simple tool to investigate effect of stringer, i.e. to show how the stress intensity factor is reduced by stiffening, contributing significantly to longer service life.

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