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ASSESSMENT OF THE INTEGRITY AND LIFE OF WELDED PANEL USING LOCAL STRESSES

PROCENA INTEGRITETA I VEKA ZAVARENOG PANELA PRIMENOM LOKALNIH NAPONA

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Ključne reči: *Metoda konačnih elemenata, zavareni panel, integritet i vek konstrukcija*

Abstract

Relevant local characteristics of fatigue loading are the largest stress amplitudes in the related mean stress values. They should be determined for the whole components. The relevant material properties are then compared with the stresses to assess integrity and life of a panel, made of Al allow, with welded stringers. To determine the maximum stresses the Finite Element Method was used.

Rezime

Relevantne lokalne karakteristike zamornog opterećenja su najveći amplitudni napon i odgovrajauća srednja vrednost napona, koje treba odrediti za celu komponentu. Relevantna svojtva materijala se onda upoređuju sa dobijenim naponima, na osnovu čega je procenjen integritet i vek panela od Al legure sa zavarenim ukrućenjem. Za određivanje najvećih napona korišćena je metoda konačnih elemenata.

1. Introduction

Panels with stiffeners represent a typical load carrying component in aeronautical structures, both under static and fatigue loading, [1-2]. It is a critical component, made of Al alloy, with no option in respect to failure, it simple has to sustain the load. Therefore, its integrity and life has to be carefully and precisely determined. There are two basic types of panels, so-called differential, with stiffeners attached to panel by screws, and the other, so-called integral, with stiffeners welded to panel, [1]. Two welding processes have been used recently for this purpose, Friction Stir Welding (FSW) and Laser Beam Welding (LBW), [3]. It has been show that the integral panel can have significantly longer life and sustain better the loading, even in presence of cracks [1].

In this paper, AA6156T6 panel with laser welded stiffeners is analysed numerically by the Finite Element Method (FEM) to obtain the largest stresses in static loading and the largest stress amplitudes in the case of fatigue loading. They are then compared with corresponding material properties to assess its integrity and life.

2. Numerical simulation

The software WB/FKM-Weld (FKM inside ANSYS) allows strength assessments based on the FKM Guideline “Analytical Strength Assessment of Components in Mechanical Engineering”. As mentioned above, the guideline covers assessments of static strength and fatigue strength for components under mechanical loading. Results of CAE simulations are commonly used to determine the local stresses for the assessment. WB/FKM-Weld performs assessments based on the FKM Guideline for all selected welds of a component. In a graphical user interface, user defines additional settings required for the weld assessments. The necessary model information is used from ANSYS Workbench [4, 5]. Load combinations are automatically defined based on the load steps and loading types defined in ANSYS Workbench. The software analyzes the worst load combination for every node of the finite element mesh. The result of the assessment, the degree of utilization, is visually shown on the finite element mesh in ANSYS Workbench, but obtained values are result of analytical procedure. WB/FKM-Weld eliminates the need to preselect critical hot-spots in an assessment and most of the manual data entries required with other software tools. Result interpretation is simplified by visualizing the degree of utilization together with the relevant load combination and other data in one plot. This allows users to identify critical hotspots as well as areas allowing material savings.

WB/FKM-Weld is capable to work with different representations of weld lines within the model. Depending on the representation, the definition of the weld line is based on various kinds of selections:

- Welded parts are within one body, and no weld line is defined,
- Welded parts are separate bodies connected with contacts, and no weld line is defined,
- Welded parts are within one body, weld line is modelled,
- Welded parts are separate bodies connected with contacts, weld line is modelled.

A weld line is defined by one or more weld toes which represent the border between weld line and part. A weld toe may consist of one or more geometrical edges. Some assessment parameter can be associated separately to each edge, others to the complete weld line. Figure 1 shows weld toes and geometrical edges, for two options, modelled and not modelled weld line.

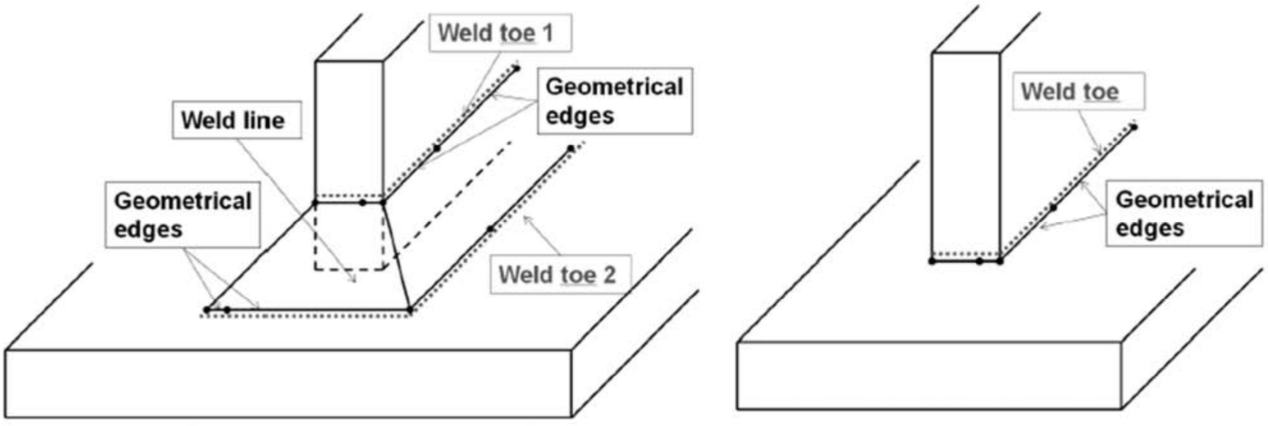


Figure 1. *Weld toes and geometrical edges*

Slika 1. *Metal šava i njegove geometrijske granice*

In addition, the extrapolation surfaces attached to the weld toes have to be defined (Figure 2). An extrapolation surface might be associated to more than one geometrical edge of the weld toe.

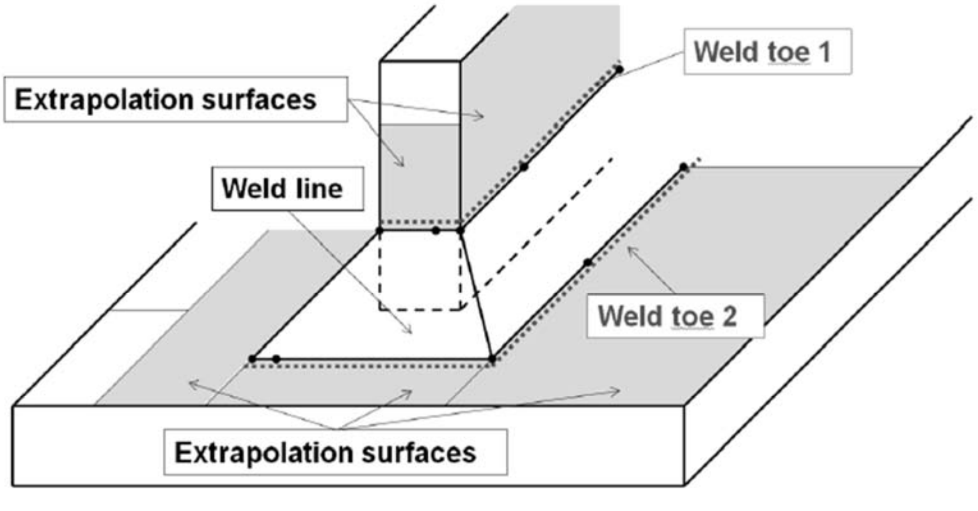


Figure 2. *Weld toes and extrapolation surfaces*

Slika 2. *Metal šava i ekstrapolacione površine*

Geometry of the panel that was analyzed using WB/FKM-Weld is shown in Figure 3. Loads and boundary conditions applied matched those used in experimental analysis [6]. Stringers are connected with the base plate using laser beam welding.

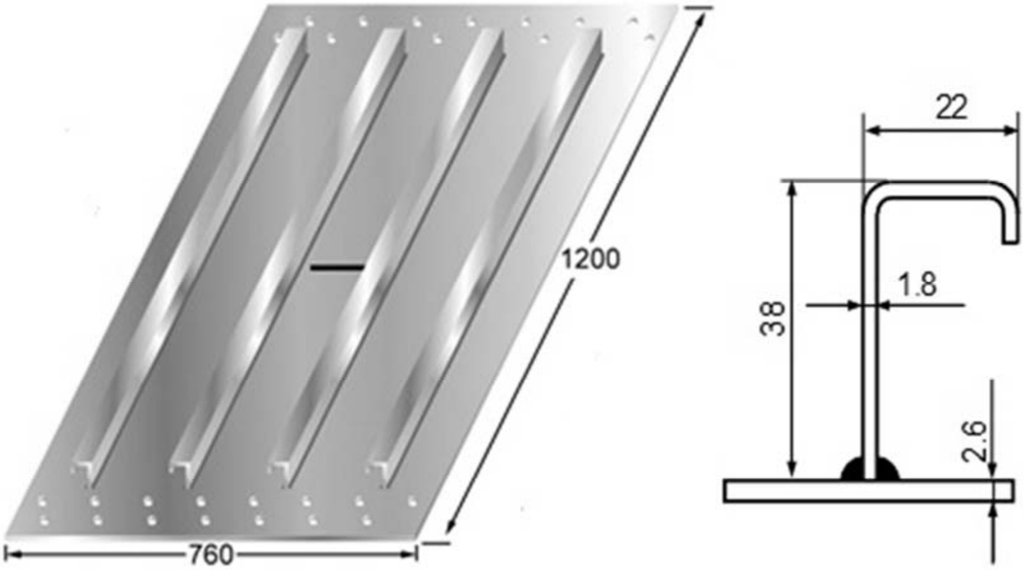


Figure 3. *Dimensions of the 4-stringer panel made of AA6156-T6 aluminum*

Slika 3. *Dimenzije ploče sa četiri ukrućenja izrađene od aluminijumske legure AA6156-T6*

Model of panel with 4 stringers, welded to a base metal made of AA6156 T6, with details of FE mesh is shown in Figure 4.

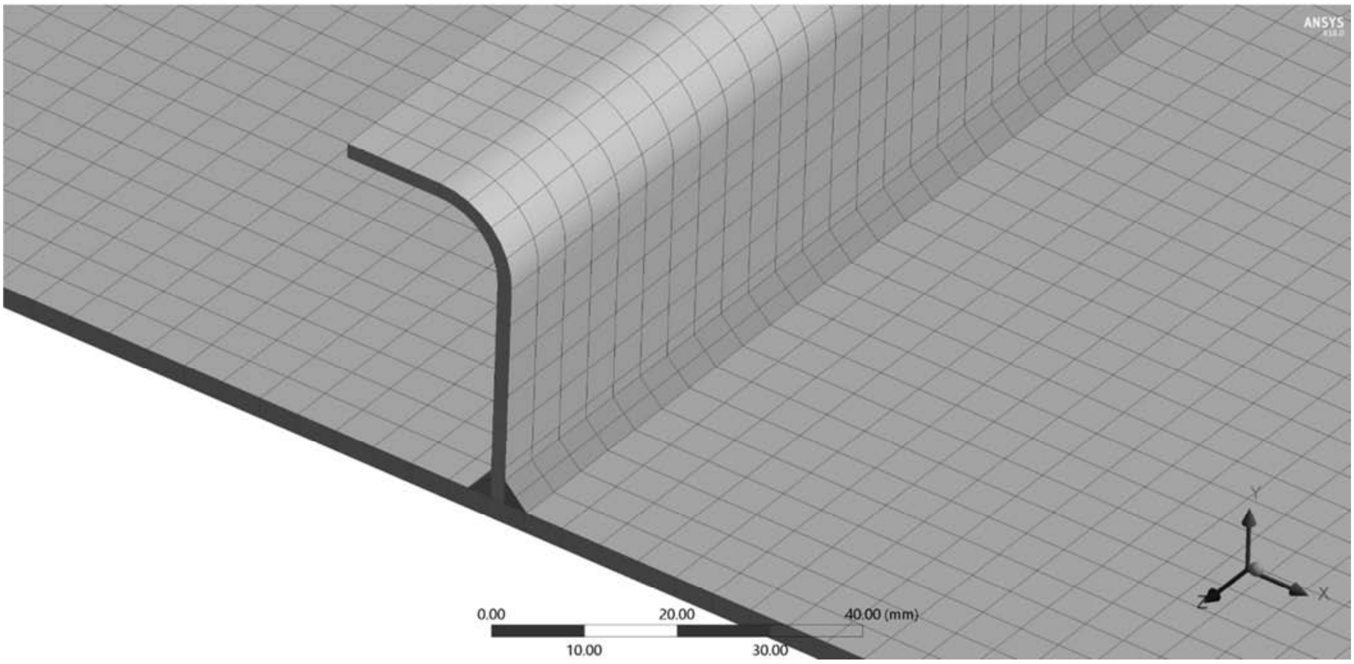


Figure 4. *Details of mesh of 4-stringer model with the weld line.*

Slika 4. *Detalji mreže modela sa četiri ukrućenja sa linijom zavarivanja*

Figures 5 and 6 show toes and surfaces for each stringer and base metal. Figure 7 shows all weld connections and settings of weld lines, as well as construction properties, weld type and quality, and properties of S-N curve of material used for welding. In fatigue assessment of weld joint number of cycles used was $5 \cdot 10^6$. Figure 8 shows additional fatigue properties.

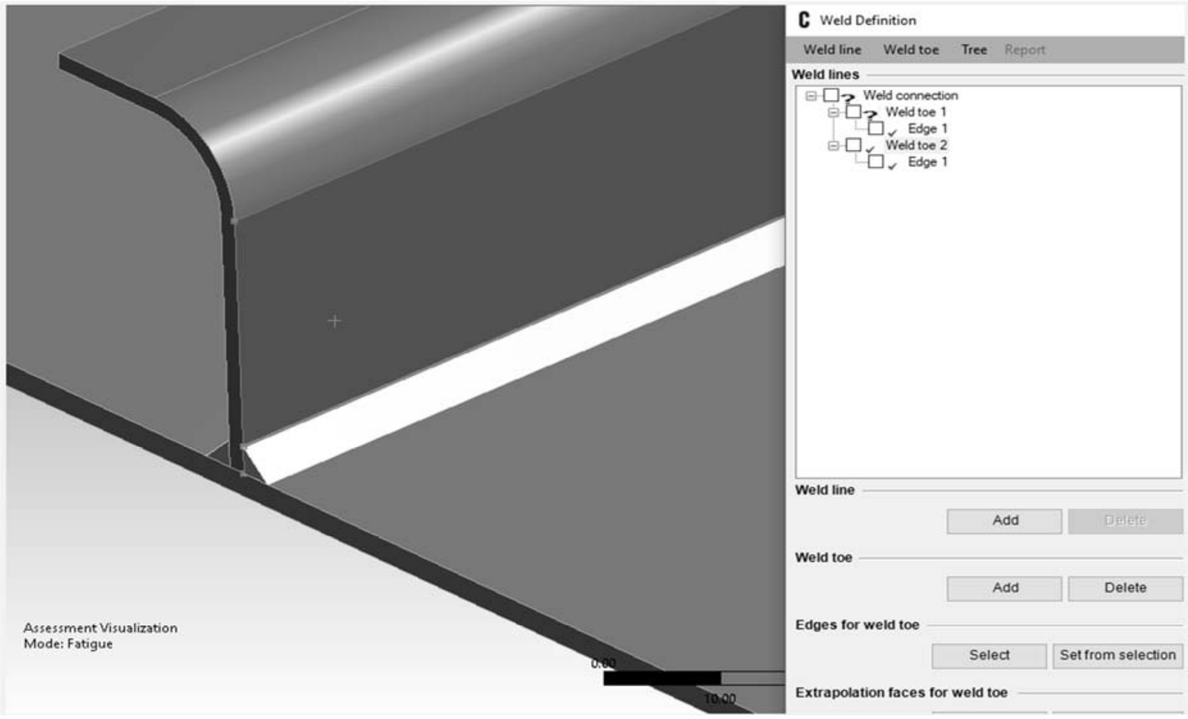


Figure 5. *Weld toe and extrapolation surface defined on stringer*

Slika 5. *Metal šava i ekstrapolaciona površina definisani na ukrućenju ploča*

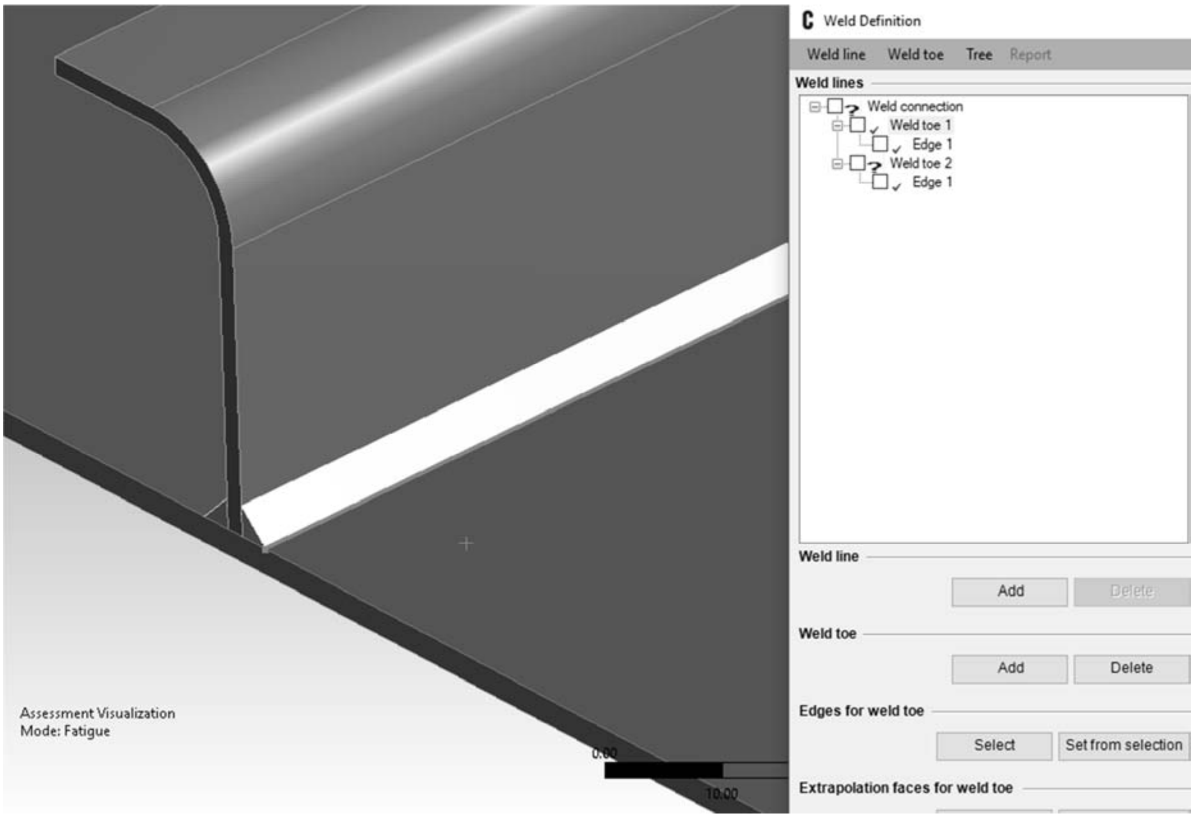
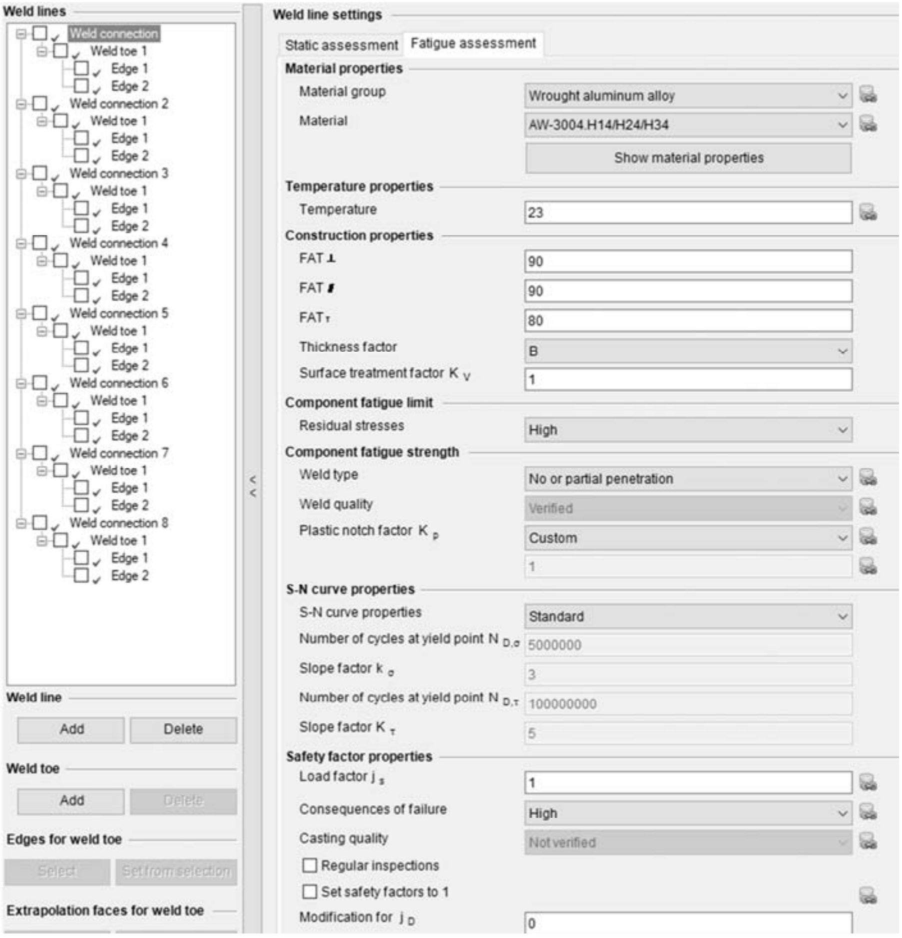


Figure 6. *Weld toe and extrapolation surface defined on base metal*

Slika 6. *Metal šava i ekstrapolaciona površina, definisani na osnovnom metalu ploče*

After completely defining weld lines and external force (115 kN, Fig. 9), boundary conditions (Figures 10 and 11) are applied in accordance with the experiment [6].



Weld line settings

Fatigue assessment

Material properties

Material group: Wrought aluminum alloy

Material: AW-3004.H14/H24/H34

Temperature properties

Temperature: 23

Construction properties

FAT ⊥: 90

FAT ∥: 90

FAT τ: 80

Thickness factor: B

Surface treatment factor K_V: 1

Component fatigue limit

Residual stresses: High

Component fatigue strength

Weld type: No or partial penetration

Weld quality: Verified

Plastic notch factor K_p: Custom

1

S-N curve properties

S-N curve properties: Standard

Number of cycles at yield point $N_{D,\sigma}$: 5000000

Slope factor k_σ: 3

Number of cycles at yield point $N_{D,\tau}$: 100000000

Slope factor K_τ: 5

Safety factor properties

Load factor j_s: 1

Consequences of failure: High

Casting quality: Not verified

☐ Regular inspections

☐ Set safety factors to 1

Modification for j_D: 0

Figure 7. *Weld definition*

Slika 7. *Definicija zavarenog spoja*

Material group

Wrought aluminum alloy

Description

5049.H24/H34 (Zusatz SG-AlMg5)

Material Properties

R_m (in MPa): 240.0

R_p (in MPa): 160.0

A (in %):

$K_{NL,E}$: 1.0

$D_{m,min}$: 0.5

$f_{\sigma,Zug}$: 1.0

$f_{\sigma,Druck}$: 1.0

ρ_{WEZ}: 0.79

$f_{w,\tau}$: 0.57735026919

α_{W1}: 1.0

α_{W2}: 1.0

α_{W3}: 0.75

α_{W4}: 0.59

α_{W5}: 0.59

α_{W6}: 0.67

Figure 8. *Fatigue properties of welding material*

Slika 8. *Zamorna svojstva dodatnog materijala za zavarivanje*

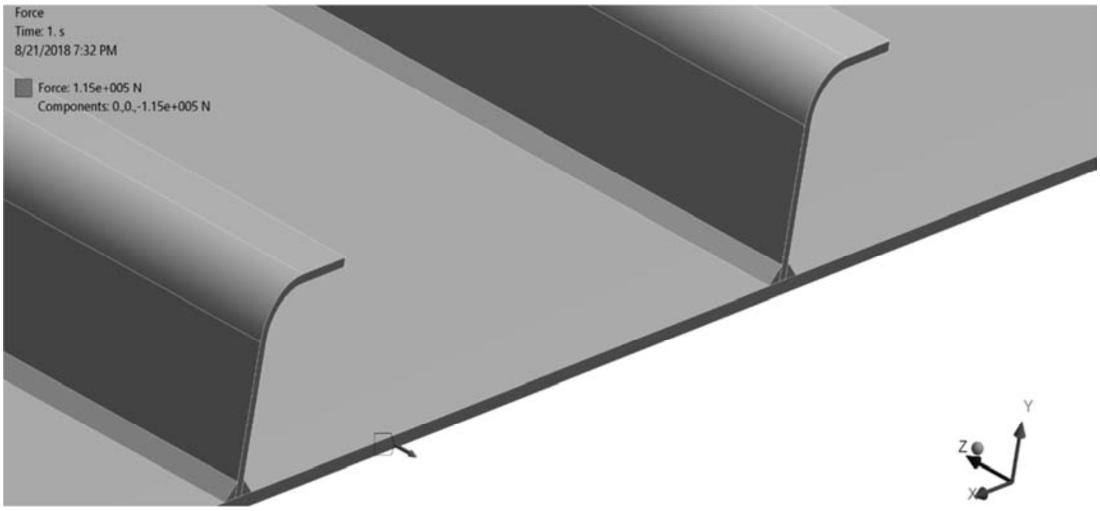


Figure 9. *Force of magnitude 115000N applied in z direction*

Slika 9. *Sila veličine od 115000N primenjena u z -pravcu*

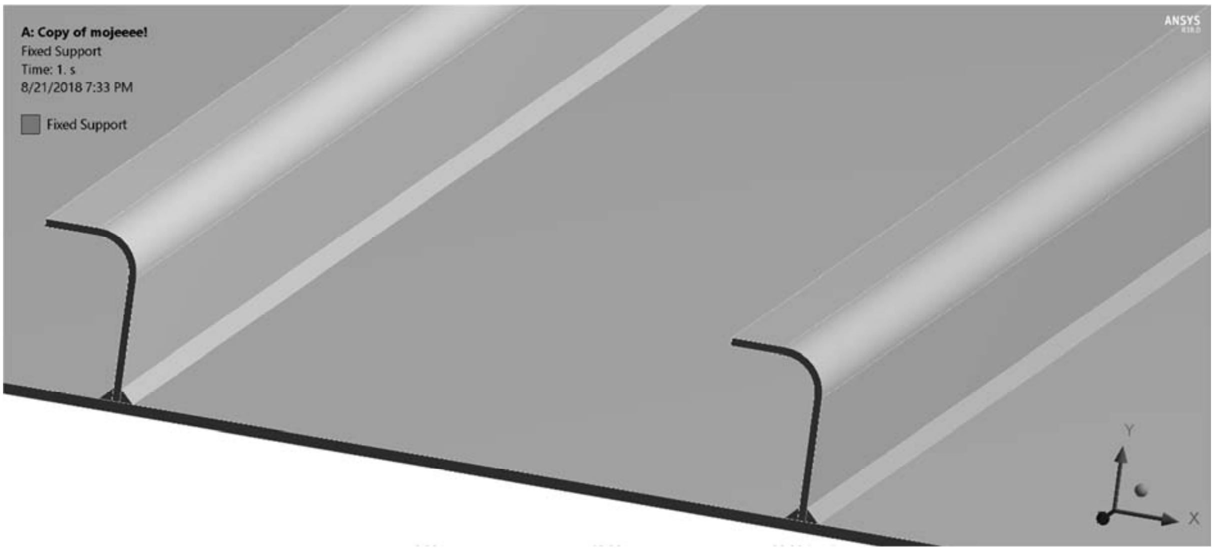


Figure 10. *One end of the base metal and stringers is fixed*

Slika 10. *Jedan kraj osnovnog metala i ukrućenja je fiksiran*

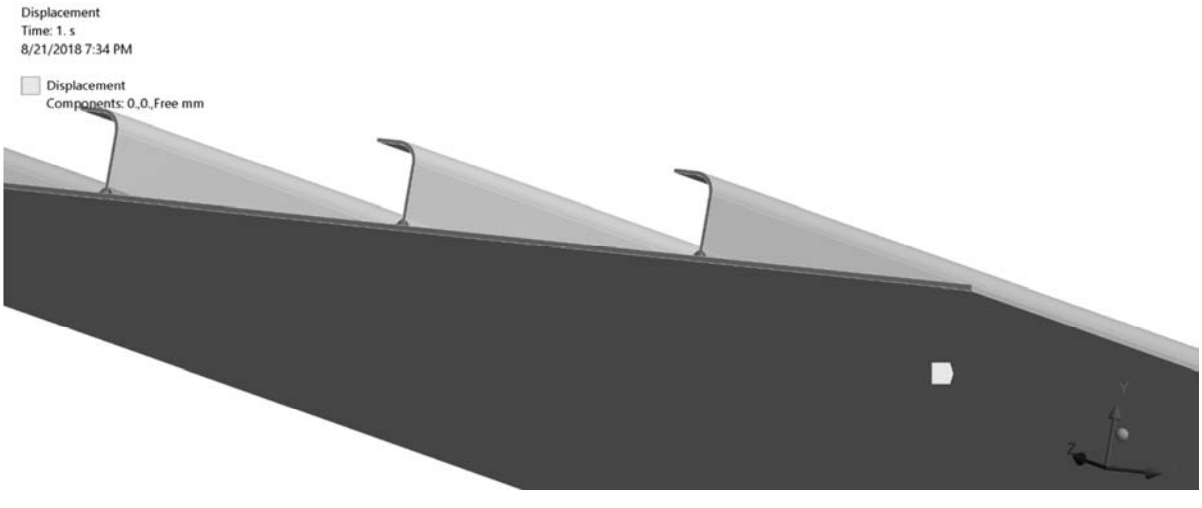


Figure 11. *Displacement applied on bottom surface of base metal (free motion in z direction)*

Slika 11. *Pomeranje primenjeno na donju površinu osnovnog metala (slobodno kretanje u z pravcu)*

3. Results and discission

Figure 12 shows strain distribution obtained by numerical simulation, while Figure 13 shows stresses, indicating uniform distribution in the middle of the plate. Strains obtained in simulation are verified by measured strains, as shown in [4]. Then, fatigue analysis of model was conducted in Ansys Workbench with amplitude e loading (stress ratio R=0.1 was taken from experiment) to simulate crack initiation in skin-stringer plate under presumed load. Analysis showed no evidence of crack initiation after 10^9 cycles (Figure 14). Nevertheless, in Chapters 5 and 6 skins-stringer plates with initial cracks were investigated, because cracks might be result of extreme loads or damage caused by unforeseen circumstances. Finally, results of WB/FKM-Weld analysis (static and fatigue strength assessment) are shown in Figures 15-17. Static strength of welded joints is satisfactory because maximum obtained value is 43.74% of the YS, which is more than two times less than limit value. On the other hand, value for fatigue strength assessment is 92% of the limit value, which implies that this weldment (all weld lines) will survive $5 \cdot 10^6$ cycles of applied load.

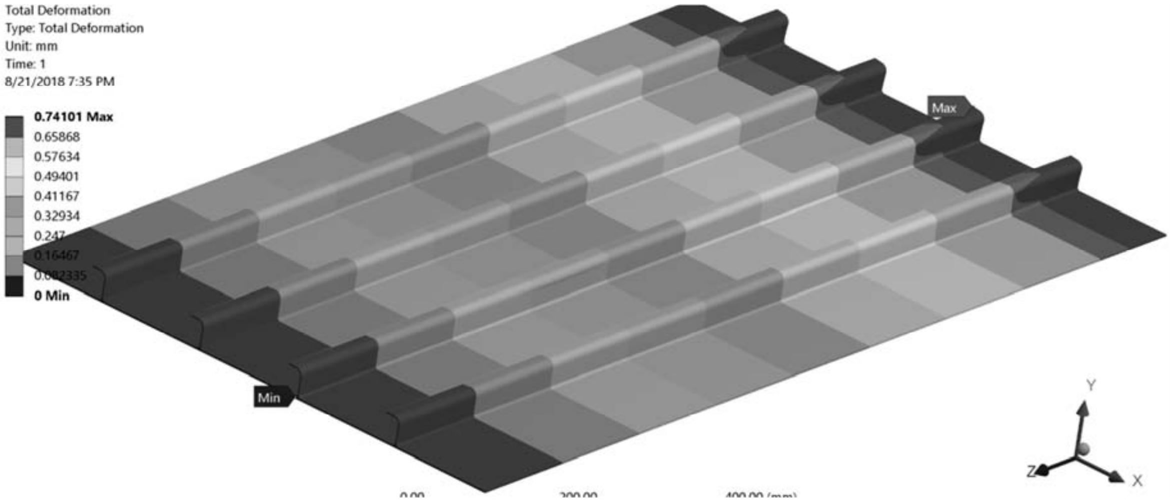


Figure 12. *Distribution of skin-stringer plate strains*

Slika 12. *Raspodela površinskih deformacija na ukrućenjima ploče*

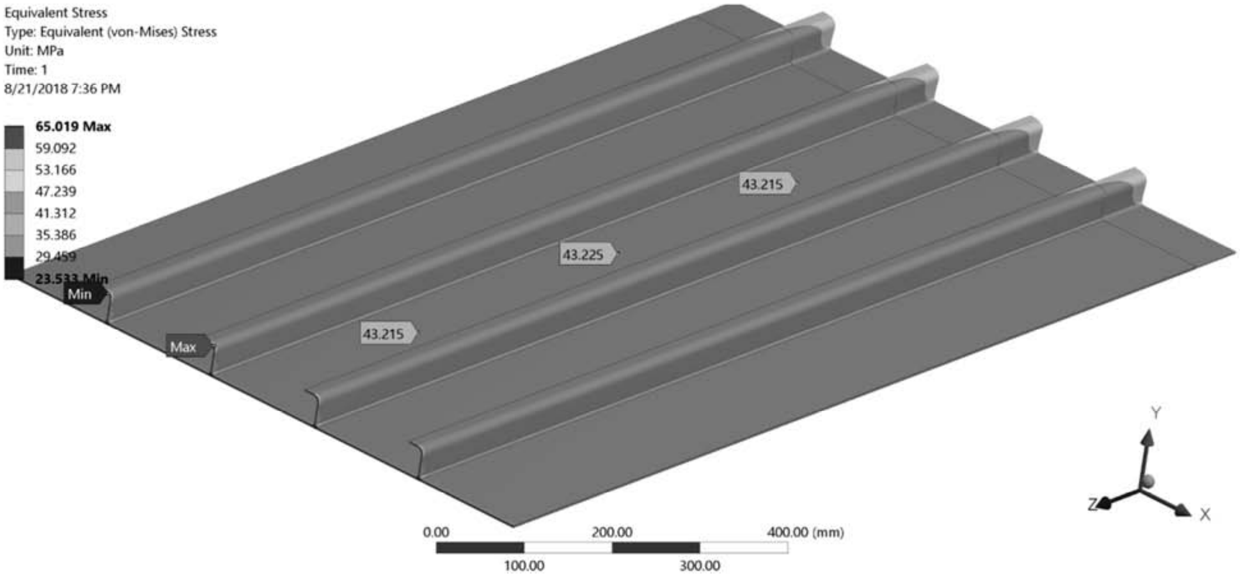


Figure 13. *Von Mises Equivalent stresses*

Slika 13. *Fon Mizes ekvivalentni naponi*

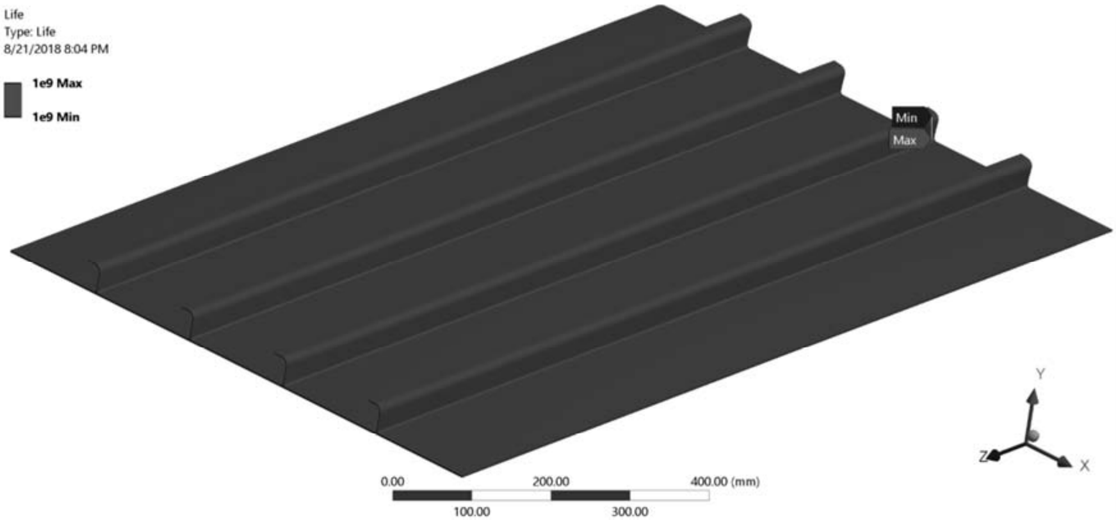


Figure 14. *No evidence of crack initiation after 10^9 cycles of applied load (R=0.1)*

Slika 14. *Nema prisustva inicijacije prslina nakon 10^9 ciklusa sa primenjenim opterećenjem (R=0,1)*

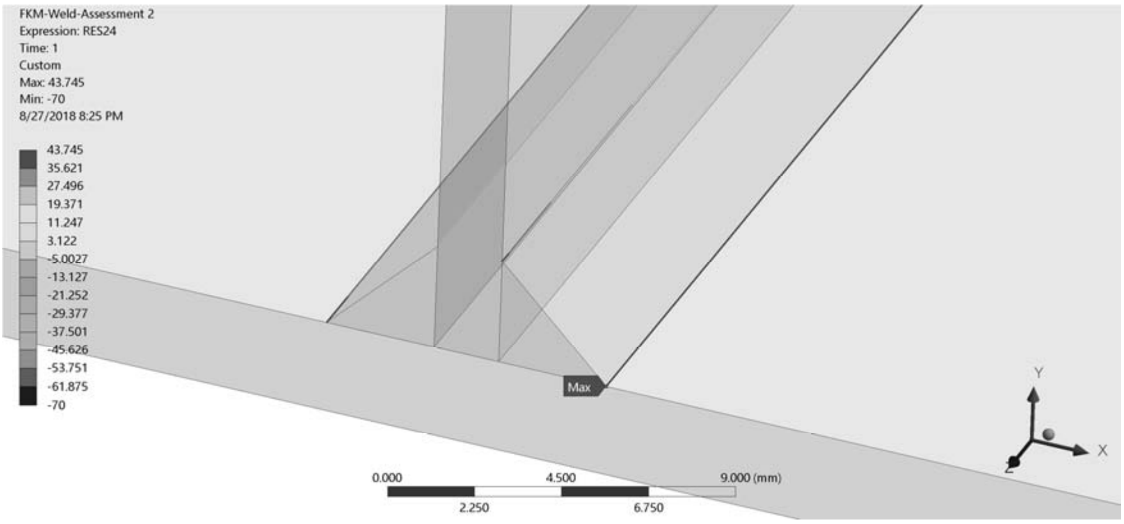


Figure 15. *Static stress and strength ratio assessment of weld lines*

Slika 15. *Procena odnosa statičkog napona i čvrstoće na liniji zavara*

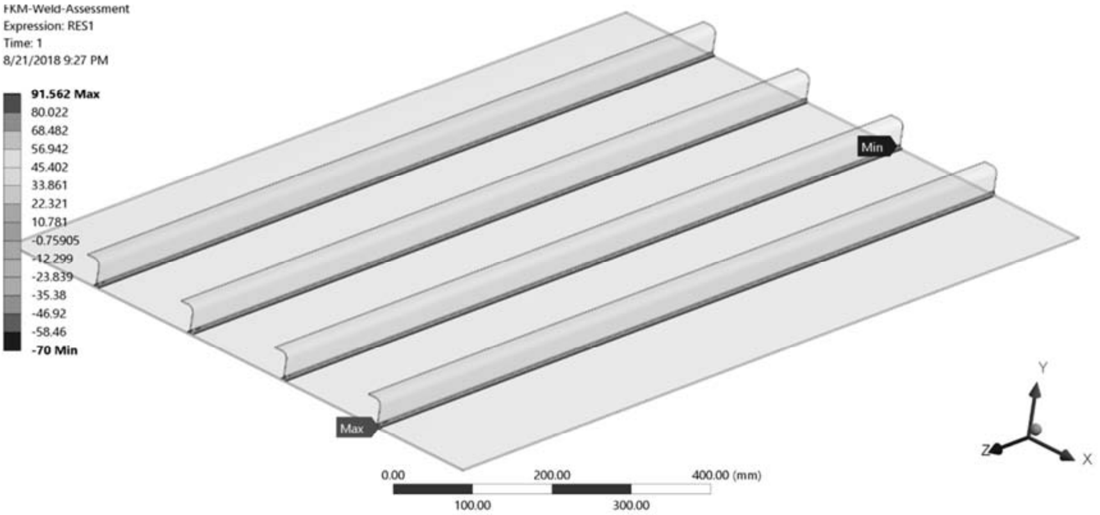


Figure 16. *Amplitude stress and fatigue strength ratio assessment of all weld lines*

Slika 16. *Procena odnosa opsega napona i zamorne čvrstoće svih linija zavara*

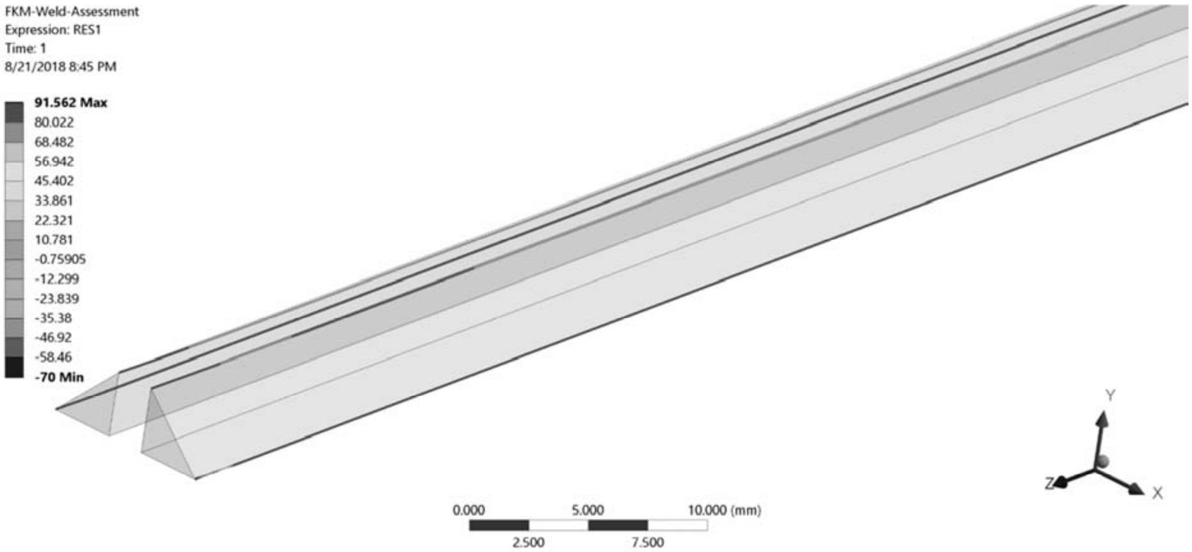


***Figure 17.** The most critical weld line*

***Slika 17.** Najkritičnija linija zavarivanja*

4. Conclusions

Based on the presented results one can conclude that numerical analysis provides efficient tool to estimate both static integrity and fatigue life of a welded component. In the case of the welded panel analysed here, it was shown that the static strength is satisfactory because maximum stress value is more than 2 times less (43.7%), as well as the fatigue strength, since it is shown that the panel will survive $5 \cdot 10^6$ cycles under maximum amplitude load.

4. Zaključci

Na osnovu prikazanih rezultata može se zaključiti da numerička analiza predstavlja efikasan alat za procenu statičkog integriteta i zamornog veka zavarene komponente. U slučaju analizirane zavarene ploče, pokazalo se da je statička čvrstoća zadovoljavajuća, jer je maksimalna vrednost napona, više od 2 puta manja (43,7%), kao i zamorna čvrstoća, jer je pokazano da će ploča izdržati $5 \cdot 10^6$ ciklusa pod maksimalnim amplitudnim opterećenjem.

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