Investigation of Welded Joints in Finite Element Analysis

Osman Bahadır ÖZDEN [*,1], Barış GÖKÇE[2], Abdullah ERDEMİR[1]

[*]: bozden@mpg.com.tr, ORCID: 0000-0003-1231-2936
[1]: *MPG Machinery Production Group Inc. Co., Konya, Turkey*
[2]: *Engineering Faculty /Mechatronics Engineering, Necmettin Erbakan University, Konya, Turkey*

Abstract: Regions with the lowest fatigue life in a welded joint are usually formed at the weld toe or weld root. It is important to carefully examine the welded joint region, especially for structures exposed to high moments and forces. While evaluating welded joints in finite element method (FEM) analysis, it can be evaluated according to International Institute of Welding (IIW). According to IIW, there are four approaches to evaluate the stresses on the welded joint: the nominal stress approach, the structural hot spot stress approach, the effective notch stress approach and the linear elastic fracture mechanics' approach. In large and complex structures, modeling of welded joints in FEM analyzes affects the time spent for analysis. Therefore, preferred approach for modeling and evaluation is important for the time spent. The accuracy rate, on the other hand, varies according to the chosen approach, and investigations should be made according to the complexity of the structure being analyzed and the type of stress coming to the examined region. Although the accuracy rate is closest to the linear elastic fracture approach, this approach is not preferred because it will require a lot of effort in FEM analysis, especially in complex structures. In this study, conventional approaches proposed by IIW were examined while performing welded joints in FEM analysis. These investigations were carried out in the welded region with the most critical stress on a mobile crane machine. According to the results of the study, the hot spot stress was found to be 693 MPa and the nominal stress was 515 MPa according to the maximum principal stress in this region.

Keywords: *Welded Joints, Hotspot Stress, Finite Element Analysis, Estimation Fatigue Life.*

I. INTRODUCTION

WELDED joints are usually the connections with the lowest fatigue life for structures. For this reason, welded joints are important for a reliable design and durability [1]. Although many discontinuities occur in the weld pool during welding process, they can be controlled by non-destructive tests such as penetration test, magnetic particle test, ultrasonic inspection. All processes applied during the welding process affect the microstructure of the heat affected zone (HAZ). The structure formed in this region and the discontinuities in the weld pool affect the mechanical properties of the welded joint [2]. FEM analyzes are carried out if an experimental method is not possible while performing fatigue calculations of welded joints. Weld ends and roots of welded joints are examined and performed by FEM analysis [3, 4, 5]. Results may vary according to welded joint modeling techniques [6].

While welded joints are examined and evaluated in FEM analysis, evaluations are made with the recommendations of standards or institutions such as Eurocode 3, IIW, AWS and SSAB [7, 8, 9]. Due to the consistency of the IIW recommendations in the recently published literature studies, researches are carried out on these recommendations [10, 11, 12]. As a result of the studies, it is seen that the IIW recommendations generally give conservative results. In addition, it is seen that processes such as grinding, TIG dressing and high-frequency impact on the weld toe improve the fatigue life.

In this study, the highest stress region on the welded joints of a complex structure was found and investigated. Effective notch stress method and linear elastic fracture mechanics approach are not preferred due to high effort in such complex structures, and stress evaluations are carried out using nominal stress and hot spot stress approach. Welded joint modeling techniques and evaluation approaches were examined according to IIW recommendations, and hot spot stress and nominal stress evaluation approaches were used.

II. MATERIAL and METHODS

There are 4 approaches according to IIW recommendations for stress evaluations based on FEM analysis results in welded joints. These conventional approaches are nominal stress approximation, hot spot stress approximation, effective notch stress approximation, and linear elastic fracture mechanics approximation [13, 14]. Among these approaches, it is necessary to choose the approach according to the weld toe and weld root examinations. In the hot spot stress approach, the weld root is not examined, but can be studied in other approaches. Ansys FEM software was used in this study, and nominal and hot spot stress approaches were used for the evaluation. Accuracy rates may vary according to the chosen approach, and the choice should be made according to the complexity of the structure analyzed and the effort spent. Figure 1 shows the graph according to the complexity of the structure and the accuracy of the evaluation approach.

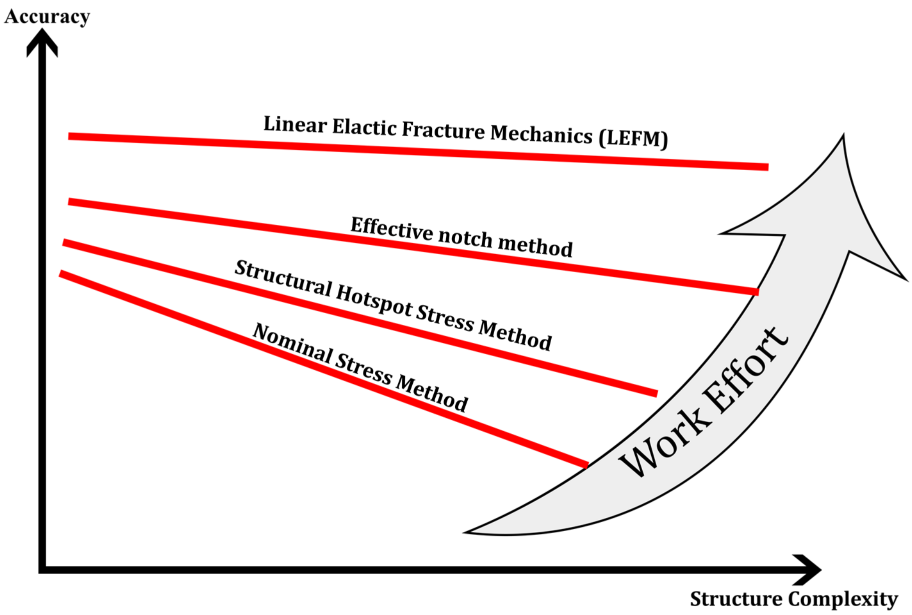

Figure 1. Stress evaluation approaches accuracy and structural complexity.

In addition, the choice of approach may vary according to the weld toe and weld root examination. There are different FAT classes of approaches when performing fatigue life calculations. Fatigue life estimates can be made with the Wöhler S-N curve and Basquin equation according to the FAT values that give the stress amplitude for the 2E+6 cycle.

A. *Nominal Stress Approach*

The nominal stress approximation is the classical evaluation method that examines the stress values in the welded joint at a location further away from the weld toe. Shell, solid, beam modelling technique of FEM can be calculated with this method. In this method, stress concentrations at the weld toe are not included. Fatigue life estimates are made with the selection of FAT classes whose stress concentrations have been verified with many samples.

The existence of many FAT classes and their use in very complex structures cause this approach to be preferred. However, it is the method with the lowest accuracy rates compared to other approaches. For the fatigue life estimations of this method, if appropriate classes are selected from the tables, quite reliable and conservative fatigue life estimations can be made. Other approaches should be preferred if nonlinear effects of weld ends are desired. Equation 1 should be used for analytical stress calculations instead of numerical analysis software such as finite elements.

$$\sigma_{nom} = \frac{F}{A_{nom}} \tag{1}$$

B. Hot Spot Stress Approach

The structural hot spot stress approach calculates the stress at the weld toe by extrapolating, taking stress values from two or three points. In this evaluation approach, there are 9 classes in the table of FAT classes. In this approach, the stress of the weld root is not examined and only the weld toe is evaluated. It gives more accurate results than the nominal stress approach, and more effort is required for weld modeling in complex structures. Figure 2 shows three methods for measuring hot spot stress in FEM analysis. (a) the method determined by linearizing the stress values in the thickness direction, (b) the method determined by taking the nodal points in the thickness direction, (c) the method that calculates the hot spot stress at the weld end by taking the stresses from the positions on the surface is shown.

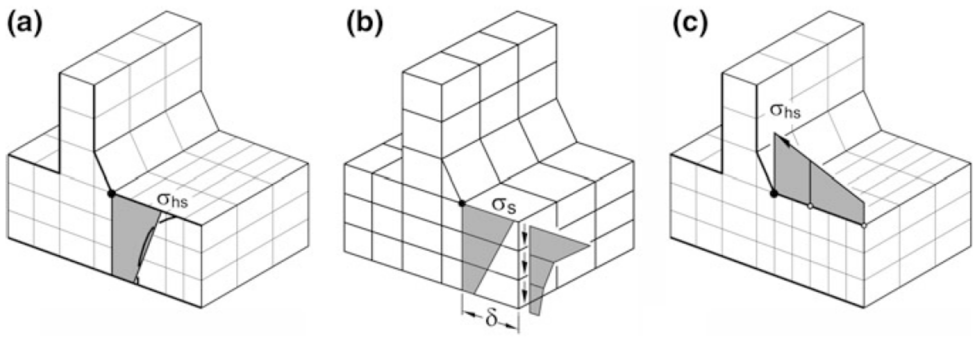

Figure 2. For hot spot stress determination; (a) by linearized stress in the thickness direction, (b) by values taken from the nodes in the thickness direction, (c) by positions over the surface [15].

In order to determine the hot spot stress, it is necessary to determine the locations where the stress values are taken. The hotspot stress points according to the fine mesh quality are specified in Equation 2 and 3.

$$\sigma_{hs} = 1.67\sigma_{0.4t} - 0.67\sigma_{1t} \tag{2}$$

$$\sigma_{hs} = 2.52\sigma_{0.4t} - 2.24\sigma_{0.9t} + 0.72\sigma_{1.4t} \tag{3}$$

C. Effective Notch Stress Approach

In the effective notch stress approach, the weld toe is modeled with a 1 mm radius according to IIW recommendations and the evaluation is made. In the nominal stress and hot spot stress approaches, definitions can be made with shell models, and solid modeling is performed in the effective notch stress approach. For this reason, this approach is carried out with high effort and is not preferred because it takes too much time for complex structures. In this approach, only FAT225 fatigue class is included and fatigue life estimates are made according to this value. Figure 3 shows the weld modeling for the effective notch method.

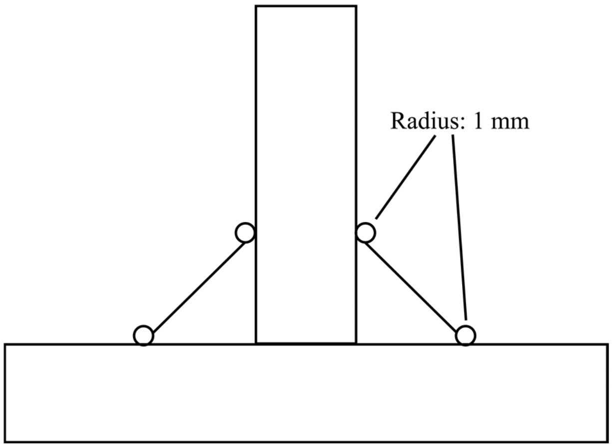

Figure 3. Effective notch stress approach weld modeling.

D. Lineer Elastic Fracture Mechanism Approach

It examines the crack formation and propagation process of welded joints in the linear elastic fracture mechanics' approach. This approach, which is examined according to stress concentration and stress density factors, can be used with Paris law and fracture mechanics approaches for samples in experimental studies. This approach is very difficult to implement especially in complex structures and is not preferred.

III. RESULTS and DISCUSSION

FEM analyzes of a mobile crane chassis were performed for welded joint stress assessments in a complex structure. In the analysis, welded joint regions are combined using a technique called share topology, which uses shell modeling. In addition, bonded contact definitions have been applied for the parts that are overlap welded. In this structure, the welded region with the highest stress was examined. Figure 4 shows the FEM analysis results of the structure.

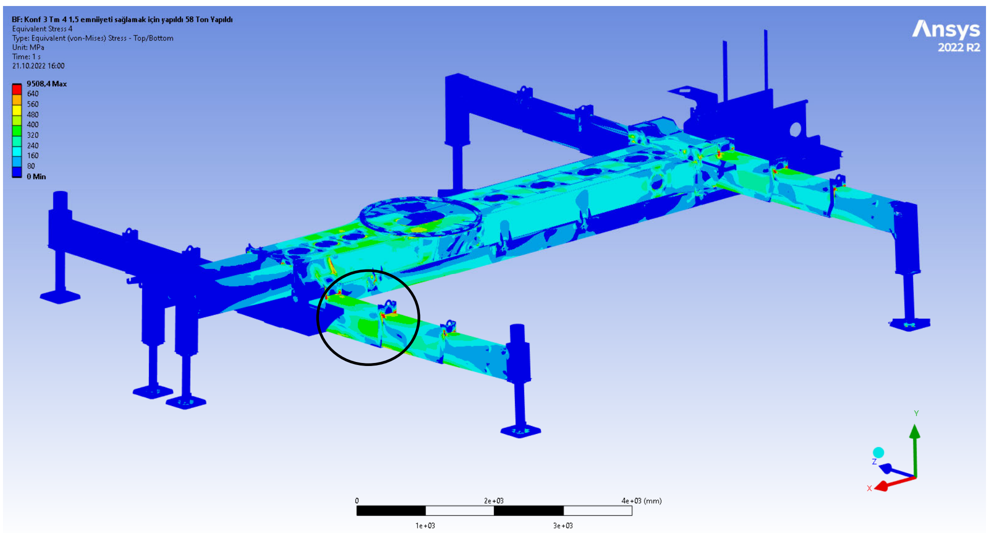

Figure 4. FEM analysis results.

As a result of the analysis, all welded joint regions were examined and the region with the highest stress was determined. In this region, definitions were made with coarse mesh modeling and investigations were carried out. Figure 5 shows this detected region.

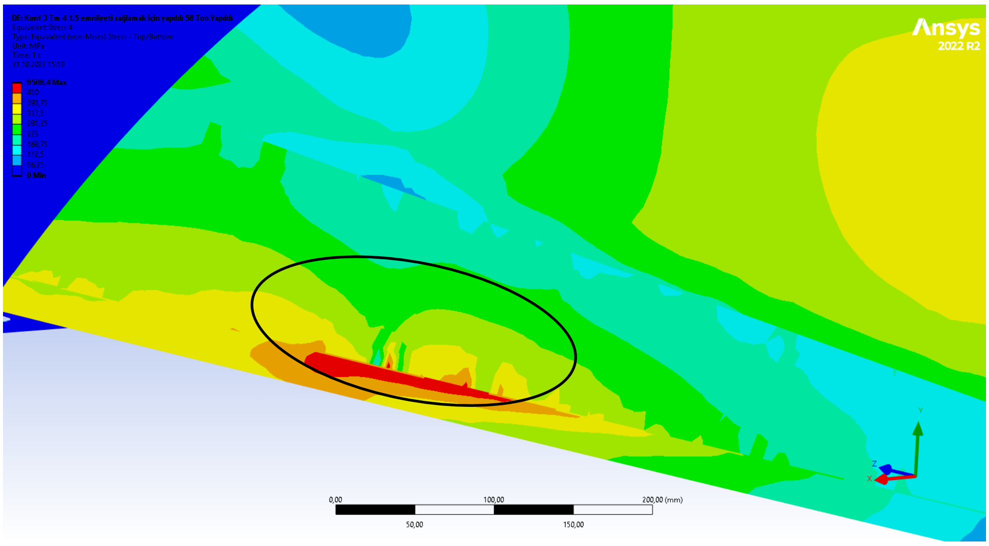

Figure 5. Detected welded joint region.

The analysis results, nominal stress and hot spot stress values for the maximum principal stress values according to the distances in the examined region are shown in Figure 6.

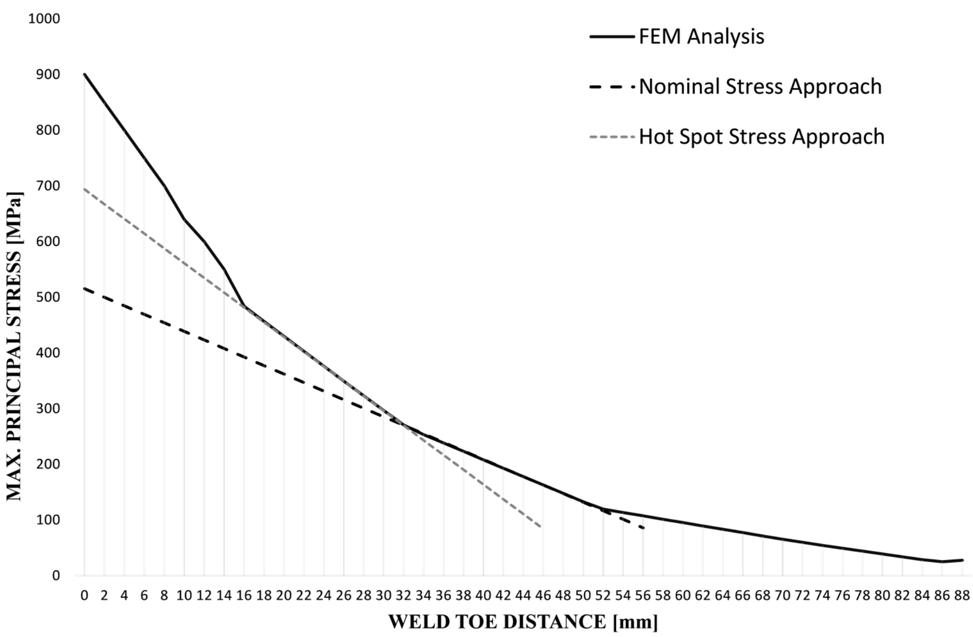

Figure 6. Detected welded joint region stress values.

As a result of the investigations, the nominal stress value for the weld toe was found to be 515 MPa. The hot spot stress value obtained with the two-point fine mesh formulation (Equation 2) was determined to be 693 MPa. According to the study [1] in the literature for a non-complex part, it was determined that the hot spot stress value was higher than the nominal stress value. Likewise, in this study, the hot spot stress value was found to be higher and evaluations were made.

IV. CONCLUSION

Welded joints are frequently used in many structures and their inspection is important for structural safety. There are many evaluation approaches for the welded joint in standards or institutions and literature and technical studies such as AWS, SSAB, DNV, and Eurocode 3. In this study, evaluations were carried out according to IIW recommendations, which are frequently confirmed in the literature. In complex structures, effective notch approach and linear elastic fracture approach are not preferred because they require a lot of effort. For this reason, nominal stress and hot spot stress values were investigated in this study. According to these approaches, an analysis model was prepared and FEM analysis was performed for a complex structure.

According to the results of the analysis, the welded joint with the highest stress was determined and this region was examined. Principal stress values up to 88 mm distance were examined by taking the welding toe as a reference. According to the analysis results, the nominal stress value was determined as 515 MPa. For the hot spot stress value, the locations were determined by using Equation 2 and the principal stress values were taken from these points. According to this equation, the hot spot stress value was found to be 693 MPa. It was determined that these results provided sufficient safety for the structure examined.

According to the results of this study, when examining the results of FEM analysis in a complex structure, it is recommended to evaluate using the nominal stress and hot spot stress approaches. With shell modeling, welded joint definitions called share topology and modeling of structures are recommended. This methodology is recommended as these approaches will provide a faster evaluation process for complex structures.

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