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The Effect of HFMI Treatment on Stress Concentration for S355J2C+N Steel with Fillet Weld Joint

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Abstract: In this study, the effect of weld toe improvement application (HFMI) on stress concentration (K_t) was investigated. Welding connection and load type specified in IIW No. 511 / FAT 80 are preferred. The structure was joined with MAG welding and S355J2C+N was used as the main material. After the HFMI application, the geometry (width: 3 mm, 3.75 mm, 4.5 mm, 5.25 mm, 6 mm and depth: 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 0.6 mm) formed at the transition from the welding tip to the base material was determined as a variable and modeled using the Creo Parametric package program. These values are referenced from the IIW recommendations document. The structure was analyzed with the finite element method using the MSC Marc package program. This scope of work; only surface improvement was focused, compressive stresses after HFMI were not modeled. Analyzes were made by changing the transition geometry, and the stress values were read for each. According to the analysis results obtained, it has been observed that the stress concentration in the transition geometry decreases with the increase in width but increases with the increase in depth. In parallel with this result, the lowest stress concentration was seen in the geometry with 6 mm width and 0.2 mm depth dimensions.

Keywords: High frequency mechanical impact (HFMI), Stress concentration, Weld toe

Introduction

As it is known, the welded joining technique has a wide area of use in the machinery manufacturing industry. Because machine parts operate under significantly variable stresses, welded joints always carry the risk of fatigue damage. Carrying out the welded joint under high heat and/or pressure and the temperature created in the weld bead being above the melting temperature of the material, causes thermal stresses in the joint. In addition, the fact that the metallurgical structure of the region under the influence of heat differs from the main material shortens the time for fatigue crack initiation and propagation in the part working under dynamic stress. As a result, the fatigue life of welded joints is always shorter than that of the base metal (Aydodu & Genel, 2002, p. 84). Therefore, various techniques have been developed to increase the fatigue life of welded joints. Weld improvement techniques can be divided into two main groups, depending on how the improvement is done. One of these is local weld geometry editing methods. In this improvement technique, local stress peaks are reduced and the surface quality is improved. The other is residual stress reduction methods. In this improvement technique, the weld is improved by reducing the residual tensile stress in cases where strain hardening or phase change occurs. Burr grinding and TIG remelting methods are generally classified as geometry improvement techniques, and the primary purpose of these techniques is to eliminate weld tip defects and reduce local stress concentration by providing a smooth transition between the plate and the weld surface. Hammer peening and needle peening methods are classified as residual stress modification techniques that eliminate the residual tensile stress in the weld tip area and create residual compressive stress in the weld tip. HFMI methods improve

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local weld geometry and surface quality while also introducing high residual compressive stress. Commonly used weld improvement techniques are shared in the Table 1 below (Marquis & Barsoum 2016, p. 4).

Table 1. Example of weld improvement methods and their main effects (Marquis & Barsoum, 2016, p. 4)

Method	Weld geometry improvement		Mechanical effects
	Increasing and smoothing transition	Eliminates defects	Induces compressive residual stresses
Grinding	x	x	-
TIG-remelting	x	x	-
Shot peening (blasting)	-	-	x
Hammer/needle peening	x	x	x
HFMI	x	x	x

Ono et al. (2022) determine the fatigue crack initiation location of high-strength steel welded joints applied with high-frequency mechanical impact (HFMI) exposed to high peak stresses in their study. They discussed the observation results of fracture samples through damage-based evaluation using the Smith-Watson-Topper parameter based on local strain.

Harati et al. (2016) investigated the effects of high-frequency mechanical impact (HFMI) treatment procedure on weld toe geometry and fatigue strength in steel welds with a fatigue strength of 1300 MPa. They are concluded that the three run treatment would be a more economical option than the six run treatment providing a similar or even more favorable geometry modification.

Aldén et al. (2020) founded that no significant influence from the HFMI operator or HFMI equipment on the fatigue life in their study. However, the scatter in fatigue testing results varied with HFMI operator and indicated that different HFMI operators could produce consistent treatment results.

In this study, the effect of weld toe improvement application (HFMI) on stress concentration (K_t) was investigated. This scope of work; only surface improvement was focused, compressive stresses after HFMI were not modeled. According to the analysis results obtained, it has been observed that the stress concentration in the transition geometry decreases with the increase in width but increases with the increase in depth.

Method

Stress Concentration

Weld constitutes a sudden change in the geometry of the joint that causes high-stress concentrations. The stress concentration is defined by the stress concentration factor K_t. The highest concentration occurs at the weld toe, which is therefore the most likely place of fatigue failure. The smaller the notch radius, the higher the stress concentration and, ultimately, the shorter the fatigue life (Fustar et al., 2020, p. 424). The stress concentration factor can be formulated as follows;

$$\sigma_{\max} = \sigma_{nom} * K_t \tag{1}$$

$$K_t = \frac{\sigma_{\max}}{\sigma_{nom}} \tag{2}$$

Geometric Model

In this study, modeling was done in the Creo Parametric package program, taking the IIW No. 511 / FAT 80 filled weld connection type as reference. Dimensions of geometric model are shown in Figure 1. Geometry (detail A) after HFMI is defined as variable and 25 models were created. Horizontal dimension of geometric model is defined as width and variable of width are used 3 mm, 3.75 mm, 4.5 mm, 5.25 mm, 6 mm. Vertical dimension of geometric model is defined as depth and variable of depth are used 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 0.6 mm.

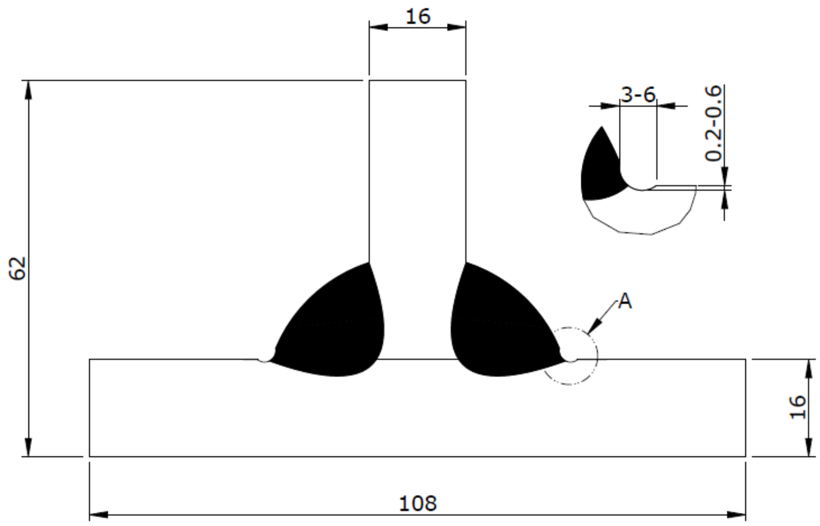

Figure 1. Dimensions of geometric model

In design S355J2C+N steel was chosen as the base material. Parts were joined by gas arc welding method and SG2 welding wire was used in these works. Mechanical properties of S355J2C+N steel and SG2 welding wire are shared in Table 2.

Table 2. Mechanical properties of S355J2C+N (Erdemir, 2020, p. 59) and SG2 (Askaynak, 2022)

	Yield Strength	Tensile Strength	Elongation
S355J2C+N	345 N/mm^2	470-630 N/mm^2	-
SG2	440 N/mm^2	540 N/mm^2	30 %

Structural Analysis

The network structure of the solid models whose designs were completed was created in the MSC Apex program. HEX8 element type was preferred as the network structure. In order to obtain realistic and consistent analysis results, a study was carried out for the most appropriate element size. Analyzes were carried out in the MSC Marc program. Analysis results; The solution time was compared considering the convergence of the obtained stresses and the number of elements used. According to these evaluations, the most appropriate network size was determined. In boundary conditions details; A fixed support is defined on the top surface of model. Tensile forces were applied to the right and left surfaces of the model. Boundary conditions are shown Figure 2.

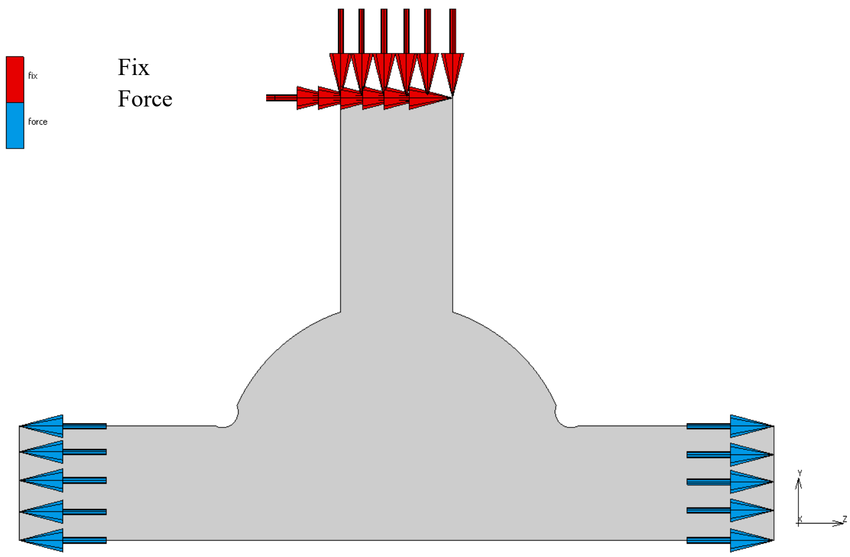

Figure 2. Boundary conditions

Results and Discussion

A total of 25 models were analyzed under the same boundary conditions. According to analysis results; nominal stress was obtained approximately 31 MPa in all models. Then, stress concentration (K_t) was calculated by the ratio of maximum stress to nominal stress for each model. All results are shared in the table 3.

Table 3. Analysis results

Model No	w *mm*	d *mm*	σ_{max} *MPa*	Kt	σ_{nom} *MPa*
Model 1	6	0.6	59.87	1.93	31
Model 2	6	0.5	57.55	1.86	31
Model 3	6	0.4	55.08	1.78	31
Model 4	6	0.3	52.50	1.69	31
Model 5	6	0.2	49.79	1.61	31
Model 6	5,25	0.6	62.53	2.02	31
Model 7	5,25	0.5	60.21	1.94	31
Model 8	5,25	0.4	57.26	1.85	31
Model 9	5,25	0.3	54.44	1.76	31
Model 10	5,25	0.2	51.70	1.67	31
Model 11	4,5	0.6	66.25	2.14	31
Model 12	4,5	0.5	63.23	2.04	31
Model 13	4,5	0.4	60.39	1.95	31
Model 14	4,5	0.3	57.35	1.85	31
Model 15	4,5	0.2	53.96	1.74	31
Model 16	3,75	0.6	70.17	2.26	31
Model 17	3,75	0.5	67.23	2.17	31
Model 18	3,75	0.4	64.08	2.07	31
Model 19	3,75	0.3	60.58	1.95	31
Model 20	3,75	0.2	56.93	1.84	31
Model 21	3	0.6	77.24	2.49	31
Model 22	3	0.5	73.45	2.37	31
Model 23	3	0.4	69.32	2.24	31
Model 24	3	0.3	65.41	2.11	31
Model 25	3	0.2	60.92	1.97	

The stress distribution graph (Figure 3) of the model with after HFMI and the as-welded model is shared.

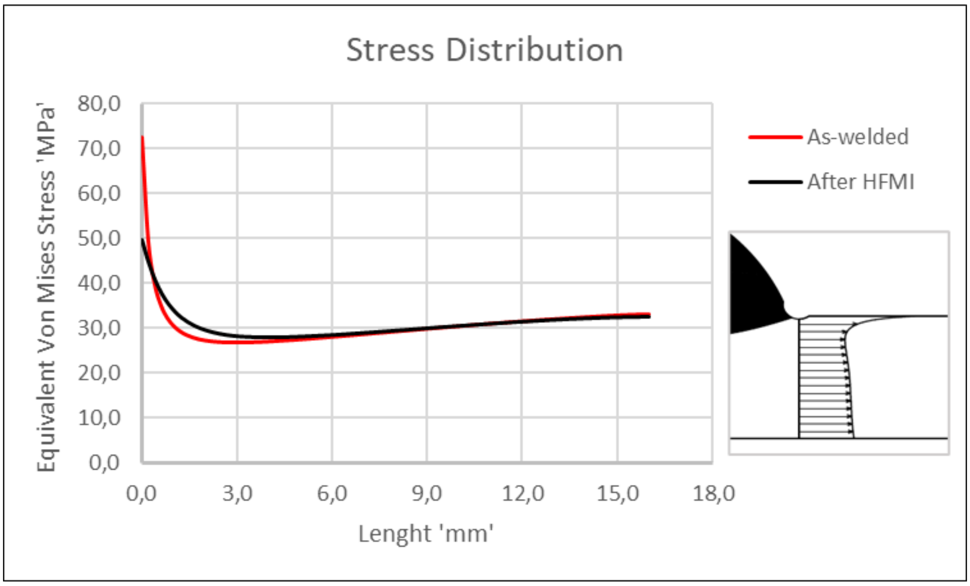

Figure 3. Stress distribution of as-welded and after HFMI

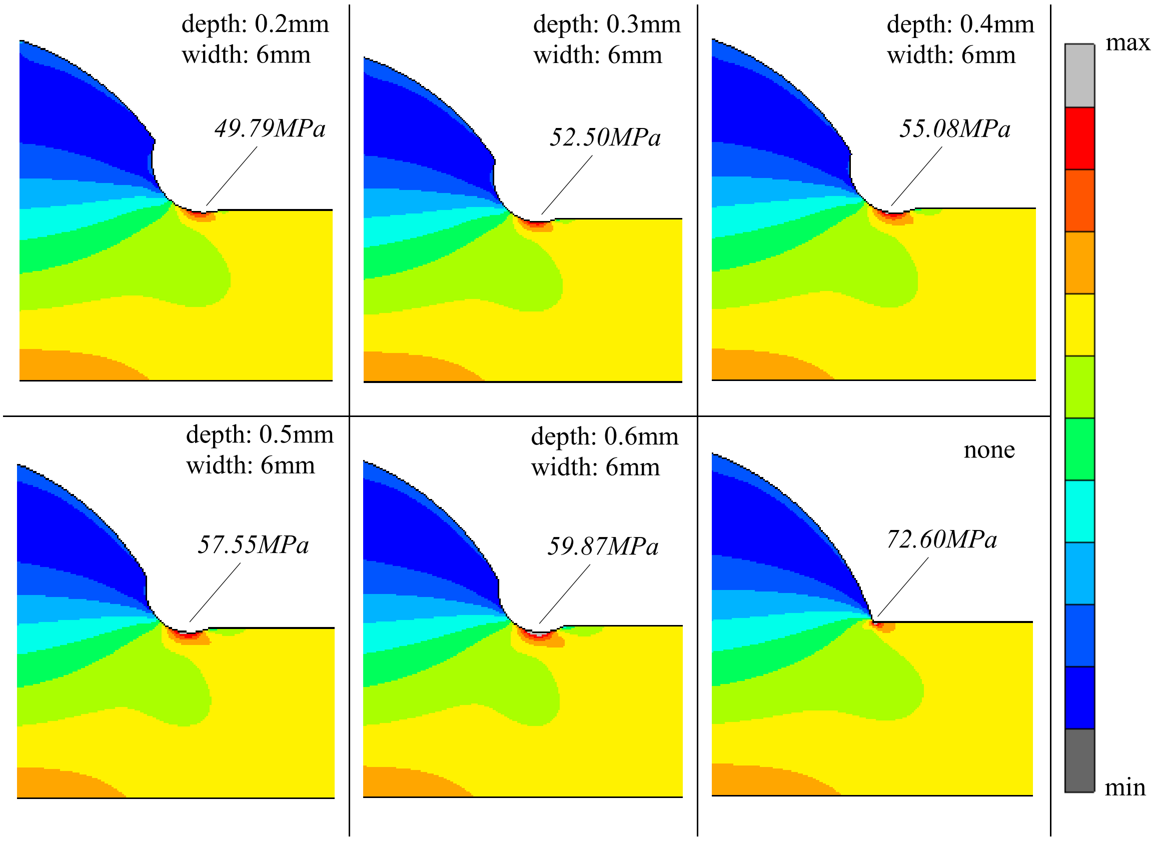

Figure 4. Comparison of as-welded and after HFMI geometries

Lowest maximum stress is 49,79 MPa between all models. Maximum stress of as-welded model is 72,60 MPa. This situation clearly showed that positive effect of HFMI application on stress concentration. When the graph is examined; in the region nearly the stress concentration, lower stresses than the nominal stress were obtained. This result is very important for fatigue life because stress amplitude used in calculation of fatigue life.

In the analysis results; maximum stress was observed as 49.79 MPa in model of depth 0.2 mm and width 6 mm, 52.50 MPa for model of depth 0.3 mm and width 6 mm, 55.08 MPa for model of depth 0.4 mm and width 6 mm, 57.55 MPa for model of depth 0.5 mm and width 6 mm, 59.87 MPa for model of depth 0.6 mm and width

6 mm. When the study is examined, width increase in geometry after HFMI caused stress concentration decreasing. The Figure 4 shows the effect of increasing the depth at a fixed width value (6mm) on the stress concentration. In addition, the stress value in the geometry without HFMI is higher than the highest stress at 6 mm width. On the other hand, there are also geometries that higher stress than the geometry without HFMI application. This situation clearly demonstrates the importance of the application level.

Stress concentration was calculated theoretically according to the stress results obtained from the analyzes (maximum and nominal stresses). According to calculations; K_t was obtained as 1.61 in model of depth 0.2 mm and width 6 mm, 1.69 for model of depth 0.3 mm and width 6 mm, 1.78 for model of depth 0.4 mm and width 6 mm, 1.86 for model of depth 0.5 mm and width 6 mm, 1.93 for model of depth 0.6 mm and width 6 mm. These values are lowest K_t for all width.

According to calculations; K_t was obtained as 1.97 in model of depth 0.2 mm and width 3 mm, 2.11 for model of depth 0.3 mm and width 3 mm, 2.24 for model of depth 0.4 mm and width 3 mm, 2.37 for model of depth 0.5 mm and width 3 mm, 2.49 for model of depth 0.6 mm and width 3 mm. These values are highest K_t for all width.

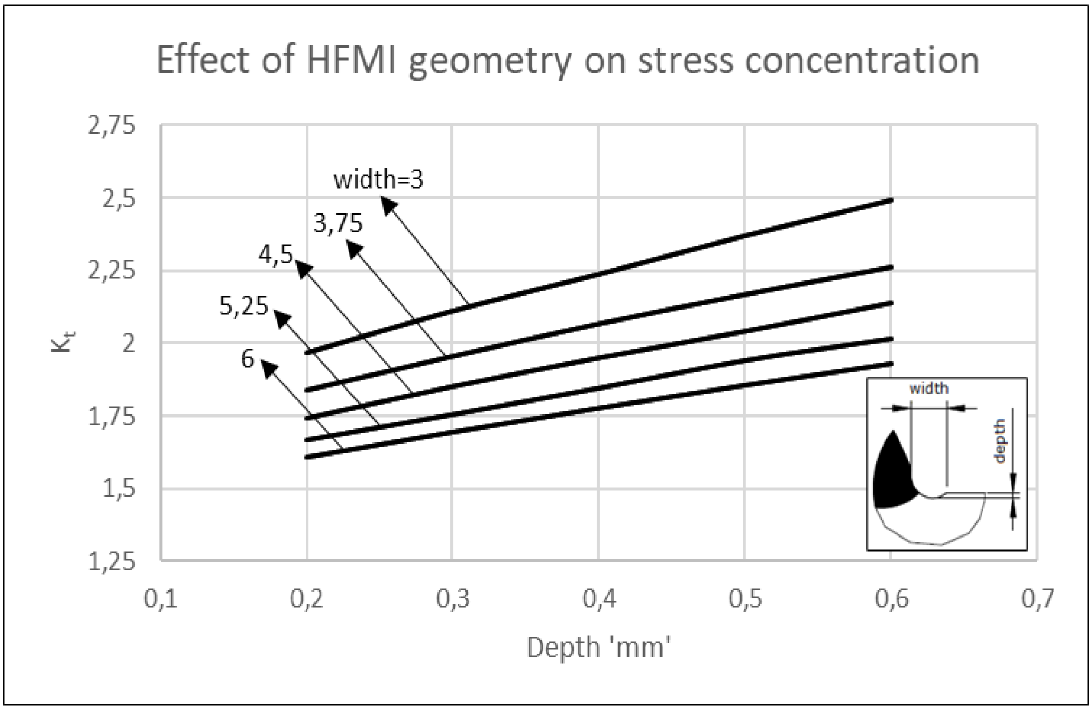

Figure 5. Effect of HFMI geometry on stress concentration

Conclusion

HFMI treatment may vary from operator to operator in practice and these situations may cause differences in the geometry after HFMI. As a result of analyses on geometry after HFMI treatment, the following conclusions were reached;

The stress concentration in as-welded geometry is higher (approximately 1.5 times) than the HFMI geometry (the model that gives the best results).

Increase of depth in geometry after HFMI caused stress concentration increasing. For all width values, the lowest K_t factor value was obtained at 0.2 mm depth value.

Increase of width in geometry after HFMI caused stress concentration decreasing. For all depth values, the lowest K_t factor value was obtained at 6 mm width value.

When all data were evaluated, the lowest K_t value was obtained at 6 mm width and 0.2 mm depth.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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