

Analysis of Stress Intensity Factor on Weld Surface

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Abstract. Progressive welding technologies based on high energy density welding process such as electron beam welding allow joining two materials without consumable. The nature of the process is the deposition of energy to the small areas, which leads to the creation of a narrow heat-affected zone (HAZ). Therefore, a prime example of surface weld defects in the case of the beam electron welding technology are cracks in the material. The article is focused on the preparation of a computational model that comprises a precise description of welding joint shape. The accurate model description was acquired using 3D scanning. In the next step, the data are subsequently modified in MATLAB and ADINA for model simplification. The performed analysis of results shows a significant influence of the weld surface on the occurrence of stress concentrations in the weld zone.

1 Introduction

3D laser scanning technology is widely used to generation of three-dimensional models with different resolution capabilities. It means that 3D models could be created for observation not only of landscape relief but also small solids either [1]. 3D scanning with a suitable device allows us to define a body surface of small solids with a relatively high density of nodes, which is also applicable for purposes of new technologies for example rapid prototyping, additive manufacturing, etc. [2, 3]. In this work, a selected 3D scanner has 3x10⁻⁴ millimeters resolution, which in terms of digitalization of body surface is appropriate to the precise description of welding joints geometry. Analyzed welding joint (Figure 1) was created by the process of laser beam welding. Measurement of surface shape of welding joint would be possible to realize by the robotic system based on contact concept or using another systems [4, 5].

In our case, the application of 3D scanning leads to a description of material surface in STL format, which contains the triangularization of scanned solid surface. The geometry of the scanned surface is shown in Figure 2. The number of nodes exceeds 996 thousand, and the number of triangles is more than 166 000.

Generated STL format was imported to program ADINA [6]. This finite element method software allows us to load the mentioned file format, however, the model cannot be modified in any-way, not even basic transformations such as rotation or shifting either.



Fig. 1. Photography of welding joint surface.

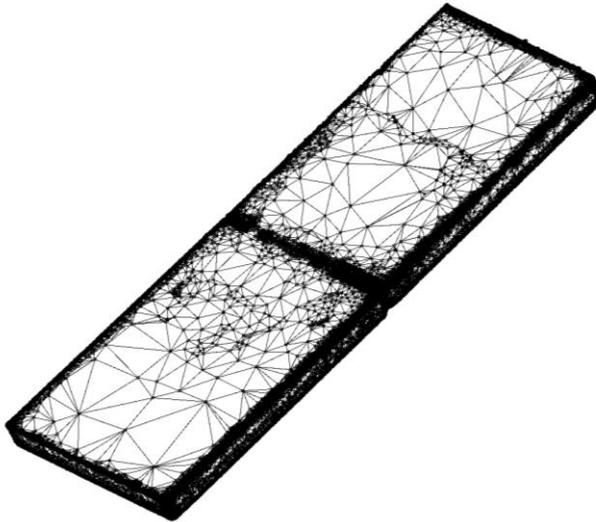


Fig. 2. 3D scan of welding joint surface.

2 Modifications of the geometric model

Modifications of the geometric model performed alternately in programs MATLAB [7] and ADINA could be described in the following steps. The first part of the modification was realized in MATLAB using a simple program. STL file is made up of a group of records with defined normal and coordinations of three points for each element of the body. The prepared program loads these definitions of every point from the STL file and also generates input files to program ADINA. Also, the program comprises a command to the successful generation of nodes, polylines, surfaces from polylines, and finally body. This method leads to a reduced number of points (242 000) and surfaces (83 000). The model is saved as a Parasolid file format because the program ADINA enables us to perform modifications of models in the aforementioned format.

In the second step, the rotation of the model was performed to set up a parallel orientation of the model with a coordination system. Subsequently, in the middle part of the model was

created rectangular prism. Using Boolean operation intersect we trimmed edges of the geometric model to create flat surfaces at the ends of the model (areas of applied boundary conditions). The intersection process results in the formation of very short edges and small surfaces in the region of trimming. The trimming process leads to the generation of small triangles (distance between nodes was approximately $1e-6$ mm). Trimming of the model significantly reduces the complexity of the model. The model before the trimming process is shown in Figure 3. After trimming, the model consists of 6600 nodes and 12 000 surfaces.

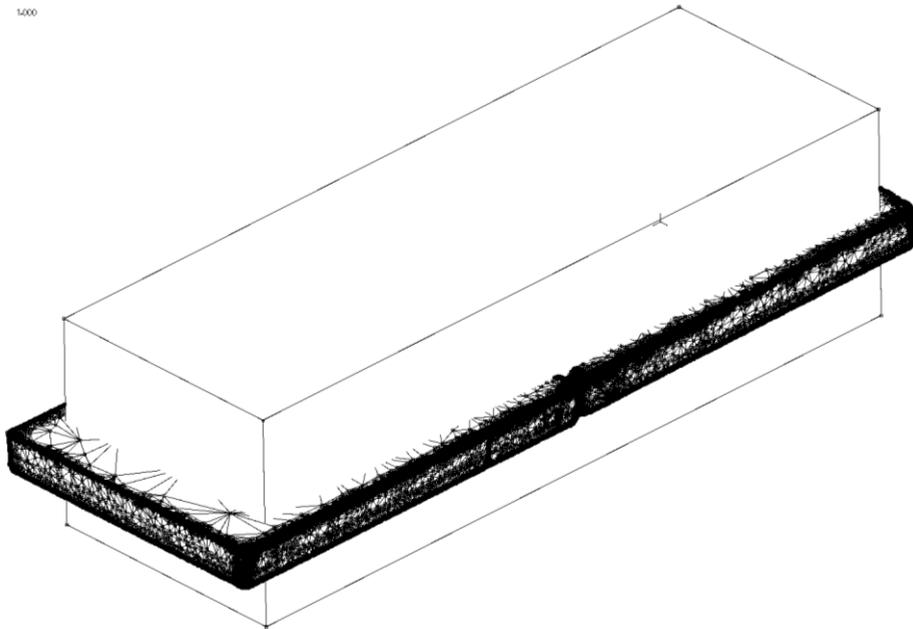


Fig. 3. Generated geometric model before trimming.

In the next step nodes were imported to program ADINA and in the case of the upper and bottom surface of the welding joint manually deleted. After the removal process, each edge in the location of trimming was checked. The controlling results to the erasure of nodes, which were identified as inappropriate (location on flat surfaces or small distances between nodes). The process was iterated several times. The outcomes of the process introduce two files, each one defines the location of nodes on the upper or bottom surface, respectively. The upper and bottom surfaces of welding are coincidentally oriented with the x-y plane. The files with location of points were imported to MATLAB to perform 2D triangularization of x and y coordinates and to generate input files to program ADINA. The sequence of commands is based on the generation of nodes, lines, and surfaces, followed by the creation of a body using a sewn command. The procedure is also repeated in the case of the upper and bottom parts of the welding joint.

The last step of model preparations comprises the importing of the bottom and upper parts of welding and generation of lateral surfaces. The lateral surfaces are created using polylines and body of type sheet. Application of sewn command results in a solid model, which was subsequently exploited in stress distribution analysis (Figure 4). The geometric model with the real described geometry of the weld is necessary for the appropriate analysis of the stress state in the welding joint [8].

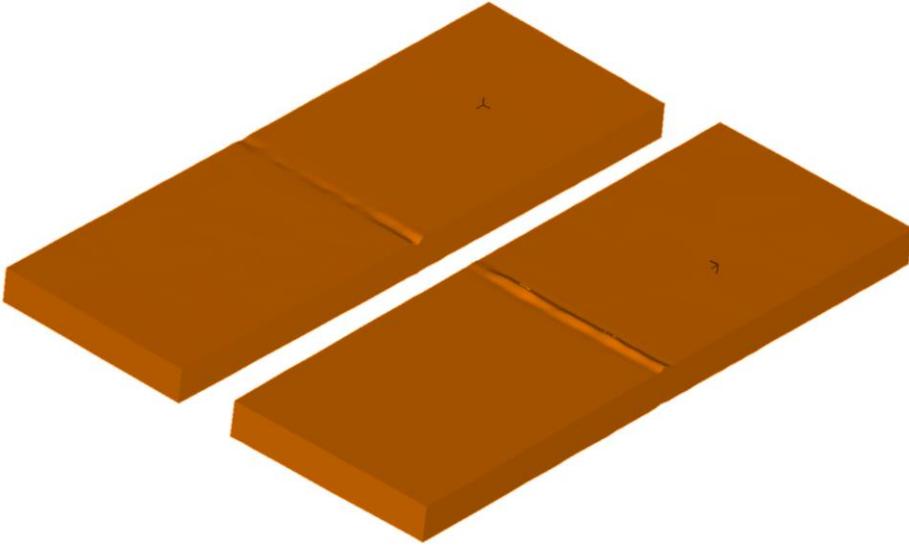


Fig. 4. Geometric model of welding joint. The model also comprises upper and bottom surfaces of joint.

3 Finite element model

The stress distribution analysis was performed on the generated geometric model. In the region of the welding joint, we determined the value of stress concentration. Therefore the loading consisted of unit tensile stress with the perpendicular orientation to the welding joint. The mesh comprises linear tetrahedral elements with sizing 1 mm. However in the welding joint area, the length of some edges is solely 0.3 mm. Determination of stress concentration coefficients is necessarily dependent on the sufficiently precise specification of stress value in a location of stress concentrations. For that reason, the authors decided to generate a finer mesh in the welding area and decreased the element sizing to 0.3 mm. It means that in the places where occur geometry variation was generated more than 30 mesh elements. Subsequently, the difference of stress is smooth and less than 5 % between two adjacent mesh elements. Therefore authors considered the selected mesh density and element type as sufficiently accurate. The selected material model was linear elastic with properties characteristic of steel. The generated mesh of the geometric model is shown in Figure 5.

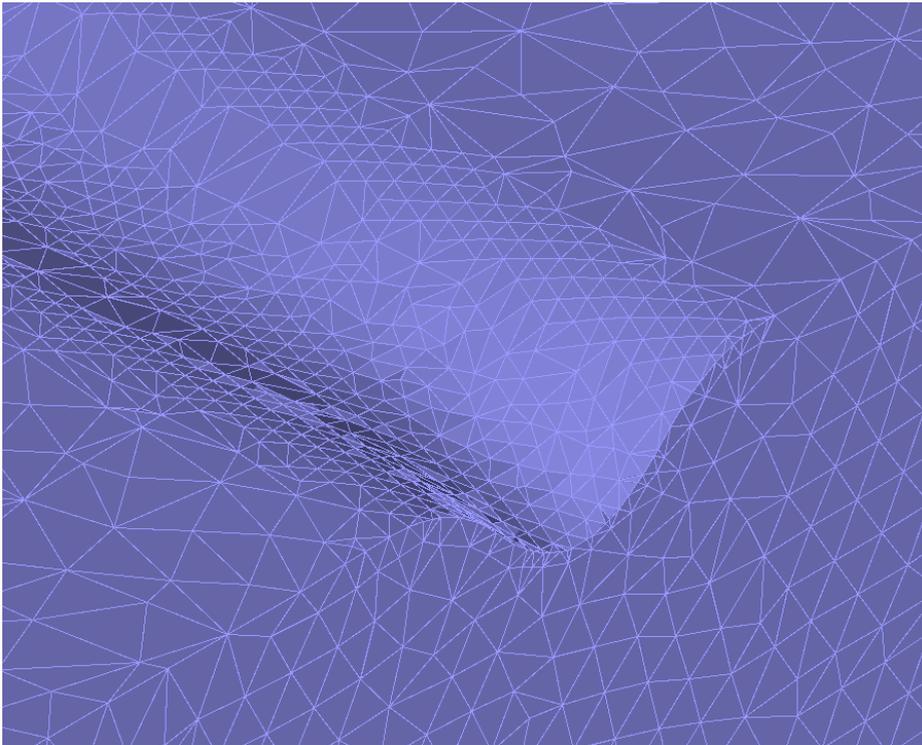


Fig. 5. Finite element mesh of welding joint.

4 Results

In the upper side of the welding joint is possible to observe a crater. According to results from FEA simulation, this undesirable result of the welding process leads to an increase in stress concentrations in this location. The figures present stress values in the x-direction (Figure 6) and von Misses equivalent stresses (Figure 7). In the latter figure are determined locations defined by numbers from 1 to 6. For these locations were specified values of stress concentration (Table 1). The value of the stress concentration coefficient equals the ratio of the stress value at the location of stress concentrator to the stress value without the presence of a stress concentrator. If the calculation is linear, the magnitude of loading could be of arbitrary value. In the linear calculation model, the Young modulus and the magnitude of loading do not influence results. In general, the loading is uniaxial pressure with a magnitude of one. Therefore the unit specification is irrelevant. The Poisson's ratio is a sole parameter, which influences the magnitude of stress tensor components. Another way to determine the stress state in welding joint is experimental measurement using an infrared camera [9].

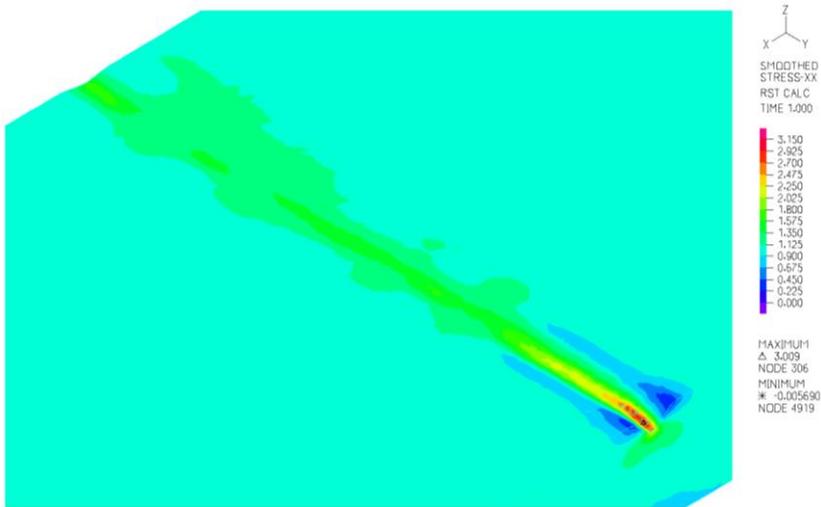


Fig. 6. Stress values in x-direction (perpendicular to welding joint).

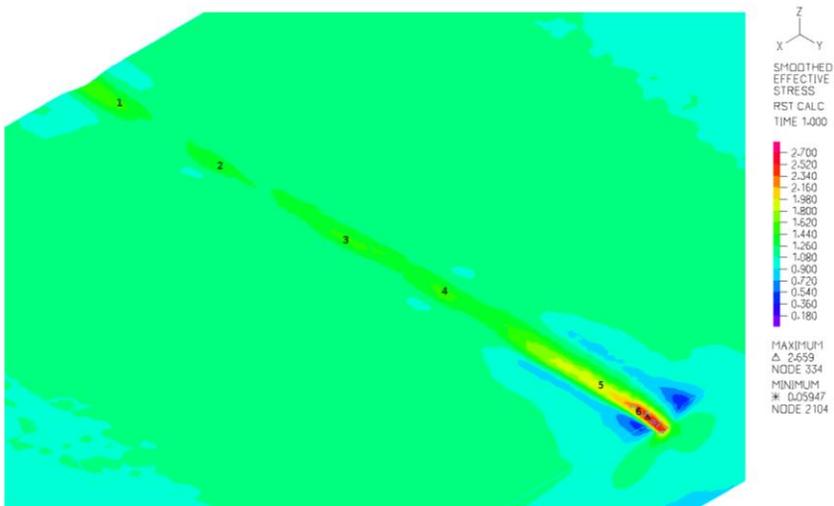


Fig. 7. Von-Mises equivalent stress.

Table 1. Relation between decrease of material thickness and stress intensity factor in specified locations of welding joint.

Location	Decrease of material thickness [%]	Stress intensity factor for stress values in x- direction [-]	Stress intensity factor calculated for von-Mises stress [-]
1	5.9	1.64	1.56
2	4.2	1.41	1.35
3	5.1	1.53	1.45
4	5.2	1.56	1.48
5	7.9	2.1	1.92
6	12.6	2.69	2.41

5 Conclusion

The generation of a computational model for stress distribution analysis with defined real geometry of the welding joint allows us to evaluate the effect of welding surface on values of stress concentration. Computations show that even with relatively small values of the change in the thickness of the material at the weld point of about 5%, the stress concentration increases to a level of about 1.5 times. Also, the difference in material thickness at the level of 8 % leads to more than a double increase in stress concentration.

Welding technologies based on a high energy density welding process without filler material forms narrow welding joints. In this case, a relatively small difference in thickness of material in the area of the welding joint causes the serious variation of geometry, which induces a significant occurrence of stress concentrations on the welding surface.

At the end of the welding joint is the difference in material thickness at the level of 12 %. In this area is possible to point out the pattern of results typical of the crack front [10]. Based on this result, we assume processes of initialization and propagation of a crack in the welding joint.

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