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A Numerical Study of the Local Stress for a Fillet with Tensile Force Applied on a Rectangular Plate

The application present a numerical study of the local stress for a fillet with tensile force applied on a rectangular plate and comparative results of the SolidWorks Simulation and experimental data, for multiple values of "H/h" ratio and "r" radius.

1. Introduction

The rectangular plate from figure 1, consisting of „Hxbx100" and „hxbx100" boxes, that are connected by the radius „r", is subjected to a tensile force F=100000 N.

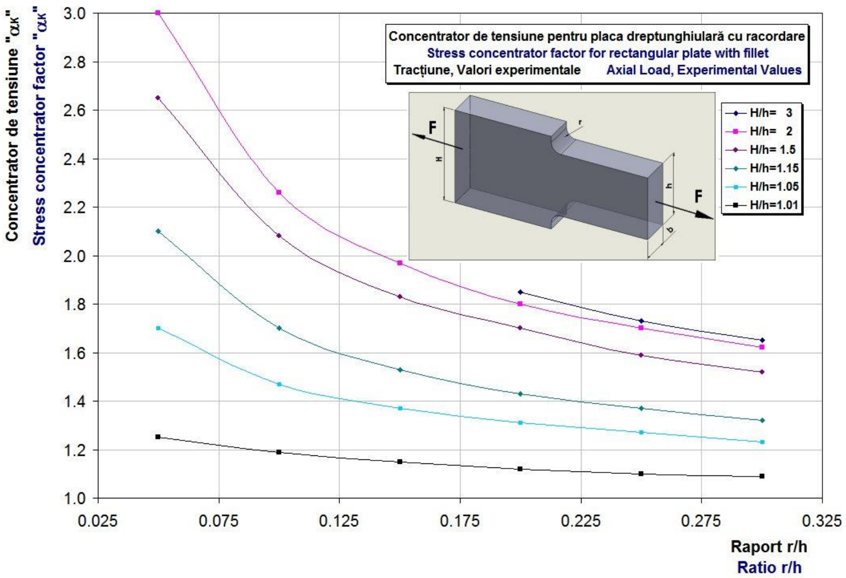

Figure 1. Stress concentrator factor.

2. Analysis

The value of maximal local stress „σ_{max}" is calculated with the coefficient „α_k" with formulas (1) and (2), where „σ_n" parameter from rel. (1) is the nominal stress value for the section „bxh", calculated with classical resistance formulas, for tensile force applied.

$$\sigma_{max} = \alpha_k \cdot \sigma_n \quad (1)$$

$$\sigma_n = \frac{F}{b \cdot h} \quad (2)$$

The experimental studies on the fillet concentrator where made for elastic regimes and statically loads. For this conditions the material will not influence the local stress value; the main parameters with influence on the local stress value are geometrical parameters of „r/h" and „H/h" ratio. The variation of „α_k" coefficient as a function of „r/h" ratio for parametrical values of „H/h" ratio is presented in fig. 3.1.1 [1], which shows the increasing influence of the „α_k" coefficient for increasing values of „H/h" ratio and reduced values of „r/h" ratio.

The formulas (3)…(8) were generated in Excel by polynomial interpolation of experimental data.

Table 1. Interpolation formula

H/h	Formula	
3	$\alpha_k = 8 \cdot (r/h)^2 - 6 \cdot (r/h) + 2.73$	(3)
2	$\alpha_k = 933.33 \cdot (r/h)^4 - 823.7 \cdot (r/h)^3 + 274.11 \cdot (r/h)^2 - 43.119 \cdot (r/h) + 4.5667$	(4)
1.5	$\alpha_k = 733.33 \cdot (r/h)^4 - 639.26 \cdot (r/h)^3 + 210.28 \cdot (r/h)^2 - 33.139 \cdot (r/h) + 3.8567$	(5)
1.15	$\alpha_k = 433.33 \cdot (r/h)^4 - 391.48 \cdot (r/h)^3 + 134.19 \cdot (r/h)^2 - 22.029 \cdot (r/h) + 2.9117$	(6)
1.05	$\alpha_k = 233.33 \cdot (r/h)^4 - 215.93 \cdot (r/h)^3 + 75.028 \cdot (r/h)^2 - 12.48 \cdot (r/h) + 2.1617$	(7)
1.01	$\alpha_k = 33.333 \cdot (r/h)^4 - 27.037 \cdot (r/h)^3 + 9.8611 \cdot (r/h)^2 - 2.2638 \cdot (r/h) + 1.3417$	(8)

The value of the parameter of H=99 mm and the boxes length of 100 mm are imposed for numerical simulation. From the following values of the „H/h" ratio: 3, 2, 1.5,1.05, 1.15, 1.05, 1.01 arise the values for „h", parameter: 33, 49.5, 66, 86.1, 94.3, 98 mm, figure 2.

From the following values of the „r/h" ratio": 0.05, 0.1, 0.15, 0.2, 0.25, 0.3 arise the values for „r" radius, fig. 12.2.

33 geometry version will be obtained, for each version it is important to calculate using numerical simulation the maximal value of local stress $\sigma_{Von\ Mises}$ for a tensile force F=100000 N applied to the "bxh" section.

For each combination "Hxh" a geometric configuration is created in SolidWorks, for which a simulation study will be performed; every simulation study will then be multiplied by 6 design studies, with the "r" radius acting as a input parameter and the stress $\sigma_{Von\ Mises}$ as a monitoring parameter.

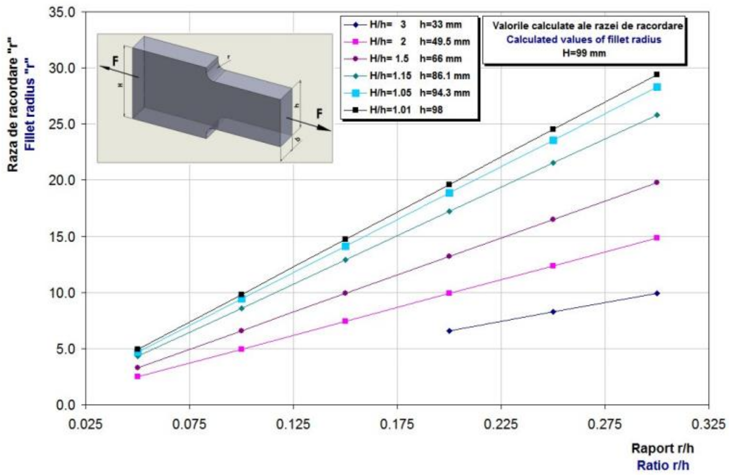

Figure 2. Fillet radius "r".

3. Application Description

- Create the geometry of plate, following stages:
  - create a new file
  - create a new sketch, a profile with dimension H=99 x 100 x 100 x h
  - extruding the profile with 15 mm
  - fillet operation.
- Creation of multiple configurations: in part documents, configurations offer the possibility to create families of parts with different dimensions, features, and properties, including custom properties. Six configurations will be created for every value of „h" parameter: h=33, h=49.5, h=66, h=86.1, h=94.3 and h=98. By default SolidWorks creates an initial configuration for any parts or assembly, with "**Default**" name, which will be renamed as "h = 33" and the parameter „h" will be changed to 33.
- Activation of the **SolidWorks Simulation** module: click **Tools** → **Add-Ins**, select **SolidWorks Simulation** module; the main menu will be provided with additional menu option **Simulation.**
- Creating a simulation and design study for every configuration. The following steps will be performed for every configuration previously created:
  - Activate the configuration; the h=33 configuration will be the first one that's activated; for this configuration the followings described steps will be performed; after which, the rest of the configurations will be activated one by one: h=49.5, h=66, h=86.1, h=94.3, h=98;
  - Create the simulation study; click **Simulation** → **Study**;

- Select the material; assign **Alloy Steel** from the SolidWorks Material library;
- Applying loads and restraints; the part is loaded with axial force F=100000 N, applied on the „hxb" face, figure 3;
- Meshing and running the simulation study. The part is divided into a number of finite elements. The maximal value of VonMises stress is obtained in the fillet region and, figure 4 for an active configuration, must be calculated for multiple values of "r" radius. Because the H and h values are fixed for every activated configuration, the values for „r" radius result for the following values of the „r/h" ratio": 0.05, 0.1, 0.15, 0.2, 0.25, 0.3. The maximal VonMises stress value is obtained by a design study where the radius "r" acts as input parameter.
- Create and running the design study. The Design Study function can generate multiple versions of the part by incrementally changing certain parameters, such as fillet radius or extrusion height. From the results, the user can pick the optimal configuration, which may be drastically different from your initial concept but still meets the required factor of safety, load conditions, stress tolerance. There are two main modes for running a Design Study:
    - **Evaluation** – to specify discrete values for each variable and use sensors as constraints; the software runs the study using various combinations of the values and reports the output for each combination. This module lets you evaluate certain scenarios of the design and see their results without performing optimization. It is possible to evaluate up to 10,000 what-if scenarios based on defined variables. If you define simulation sensors for the constraints, the simulation runs the associated studies to track the sensor values for each scenario. For the Evaluation Design Study, you can use sensors defined for static, nonlinear, frequency, buckling, and thermal studies.
    - **Optimization** - You specify values for each variable, either as discrete values or as a range. You use sensors as constraints and as goals. The software runs iterations of the values and reports the optimum combination of values to meet your specified goal.

If you plan to use simulation data sensors, you must create at least one initial simulation study before creating the design study. In our case, the evaluation design study use the "r" radius acting as a input parameter with discrete values and the stress $\sigma_{Von\ Mises}$ as a constraint parameter, subjected to a monitoring operation. First we will create the variable used in design study. The final results will be accessible through **Results View** window. The whole procedure will be repeated for the remaining five configurations.

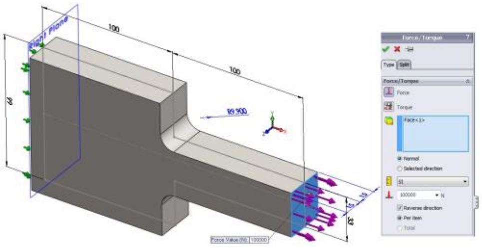

Figure 3. Applying loads and restraints.

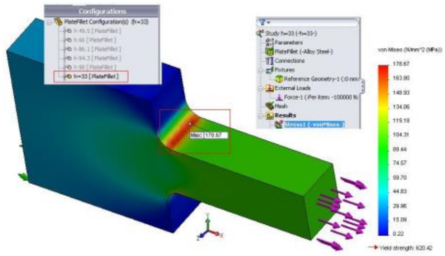

Figure 4. Maximal value of VonMises stress.

4. Comparison of Simulation and Experimental Results

The final results are shown numerically in table 2...7, where the following notations were used:

- „α_k" – the value of the experimental coefficient for „r/h" and „H/h", figure 1;
- „σ_n" – the nominal stress value calculated with formulas (2);
- „$\sigma_{max\ VonMises}$" - the maximal stress value obtained from SolidWorks design studies;
- „$\alpha_{k\,SW}$" – the numerical simulation coefficient value calculated with the formulas (9):

$$\alpha_{k\ SW} = \frac{\sigma_{\max\ Von\ Mises}}{\sigma_n} \qquad (9)$$

- Err [%] – the percentage error between the experimental and coefficient values resulted from SolidWorks design studies.

The numerical simulation results are presented graphically in figure 5 and figure 6, for both experimental and simulation coefficient values.

Table 2.

F=100000 N		b=30 mm	H=99 mm	H/h=3	h=33 mm	
r/h	r	α_k	σ_n	$\sigma_{max\ VonMises}$	$\alpha_{k\ SW}$	Err
		Experimental	Rel. (2)	SolidWorks Simulation		
-	mm	-	MPa	MPa	-	[%]
0.2	6.60	1.85	101.01	192.660	1.91	-3.10
0.25	8.25	1.73	101.01	188.150	1.86	-7.67
0.3	9.90	1.65	101.01	178.670	1.77	-7.20

Table 3.

F=100000 N		b=30 mm	H=99 mm	H/h=2	h=49.5 mm	
r/h	r	α_k	σ_n	$\sigma_{\max VonMises}$	$\alpha_{k\ SW}$	Err
		Experimental	Rel. (2)	SolidWorks Simulation		
-	mm	-	MPa	MPa	-	[%]
0.05	2.48	3.00	67.34	195.370	2.90	3.29
0.1	4.95	2.26	67.34	149.760	2.22	1.60
0.15	7.43	1.97	67.34	141.230	2.10	-6.46
0.2	9.90	1.80	67.34	131.730	1.96	-8.68
0.25	12.38	1.70	67.34	122.550	1.82	-7.05
0.3	14.85	1.62	67.34	116.760	1.73	-7.03

Table 4.

F=100000 N		b=30 mm	H=99 mm	H/h=1.5	h=66 mm	
r/h	r	α_k	σ_n	$\sigma_{\max VonMises}$	$\alpha_{k\ SW}$	Err
		Experimental	Rel. (2)	SolidWorks Simulation		
-	mm	-	MPa	MPa	-	[%]
0.05	3.30	2.65	50.51	127.590	2.53	4.67
0.1	6.60	2.08	50.51	107.340	2.13	-2.18
0.15	9.90	1.83	50.51	96.038	1.90	-3.91
0.2	13.20	1.70	50.51	93.174	1.84	-8.52
0.25	16.50	1.59	50.51	87.691	1.74	-9.20
0.3	19.80	1.52	50.51	84.088	1.66	-9.54

Table 5.

F=100000 N		b=30 mm	H=99 mm	H/h=1.15	h=86.1 mm	
r/h	r	α_k	σ_n	$\sigma_{\max VonMises}$	$\alpha_{k\ SW}$	Err
		Experimental	Rel. (2)	SolidWorks Simulation		
-	mm	-	MPa	MPa	-	[%]
0.05	4.30	2.1	38.72	73.272	1.89	9.89
0.1	8.61	1.7	38.72	67.164	1.73	-2.03
0.15	12.91	1.53	38.72	63.094	1.63	-6.50
0.2	17.22	1.43	38.72	59.824	1.55	-8.04
0.25	21.52	1.37	38.72	58.045	1.50	-9.42
0.3	25.83	1.32	38.72	56.566	1.46	-10.7

Table 6.

F=100000 N		b=30 mm	H=99 mm	H/h=1.05	h=94.3 mm	
r/h	r	α_k	σ_n	$\sigma_{\max VonMises}$	$\alpha_{k\ SW}$	Err
		Experimental	Rel. (2)	SolidWorks Simulation		
-	mm	-	MPa	MPa	-	[%]
0.05	4.71	1.7	35.35	54.929	1.55	8.61
0.1	9.43	1.47	35.35	50.169	1.42	3.46
0.15	14.14	1.37	35.35	47.760	1.35	1.39
0.2	18.86	1.31	35.35	47.238	1.34	-2.00
0.25	23.57	1.27	35.35	45.724	1.29	-1.84
0.3	28.29	1.23	35.35	44.946	1.27	-3.36

Table 7.

F=100000 N		b=30 mm	H=99 mm	H/h=1.01	h=98 mm	
r/h	r	α_k	σ_n	$\sigma_{\max VonMises}$	$\alpha_{k\ SW}$	Err
		Experimental	Rel. (2)	SolidWorks Simulation		
-	mm	-	MPa	MPa	-	[%]
0.05	4.90	1.25	34.01	44.542	1.31	-4.78
0.1	9.80	1.19	34.01	39.877	1.17	1.46
0.15	14.70	1.15	34.01	39.621	1.17	-1.31
0.2	19.60	1.12	34.01	39.752	1.17	-4.37
0.25	24.50	1.1	34.01	38.608	1.14	-3.21
0.3	29.41	1.09	34.01	38.088	1.12	-2.75

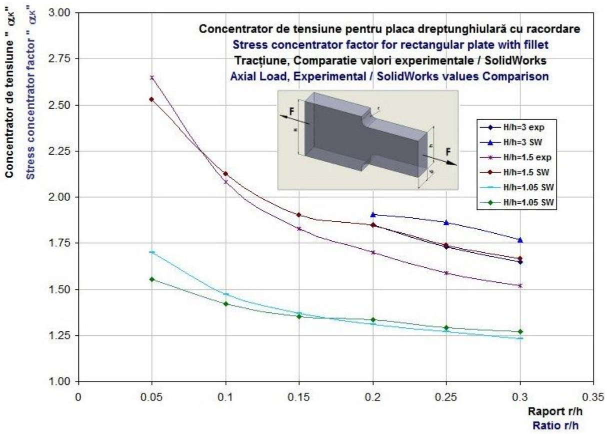

Figure 5.

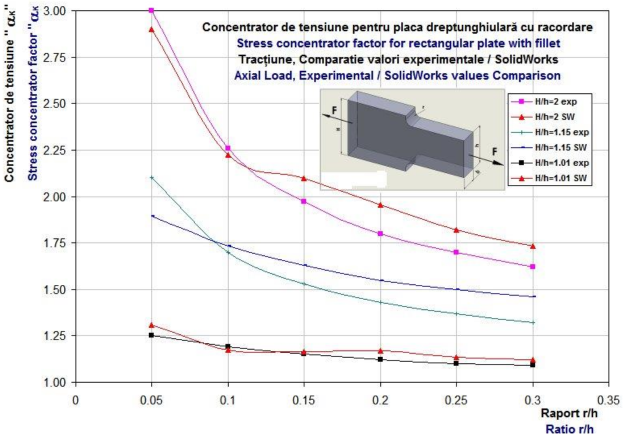

Figure 6.

5. Conclusion

The maximal value of VonMises stress is obtained in the fillet region. The local stress values resulted from the numerical simulation are comparable with the experimental values, with differences for high values of „r/h" ratio. The maximal percentage error is 10.7%, obtained for H/h=1.15 and r/h=0.3 ratio. From 33 calculated points, 18 points present values for percentage error smaller than 5%.

6. References

[1] Collins, J. A., *Failure of materials in mechanical design, analysis, prediction, prevention*, John Wiley & Sons, New York, 1981.

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