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Undercut shape optimization with genetic algorithm and FreeFem++

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Abstract. Our study examines an algorithm for searching ideal shapes of parts according to their functions and lifetime. Due to finite element method (hereinafter referred to as the „FEM“) we obtain maximal equivalent stress at critical part of component. This is the value of fitness function for genetic algorithm, which is searching for ideal shape of part according to requirements.

Introduction

By the shape optimization is possible to obtain significant decrease of stress or decrease of strain without mass grow, eventually decrease of mass without increasing of stress or decreasing of strain.

General shape optimization is a complex problem with many parameters and huge difficulty. In this paper is presented optimization of a simple construction element – an undercut. Undercut works as a stress concentrator. Stress was calculated using FreeFem++ and the shape of the undercut was optimized. As optimization criterion was stress concentration used. Undercut with circular shape is used as reference.

Description of the undercut geometry

Undercut shape was described by two different ways – as a Bezier curve with three parameters and as a polyline with n parameters (see Fig. 1). Undercut width w and depth d are fixed.

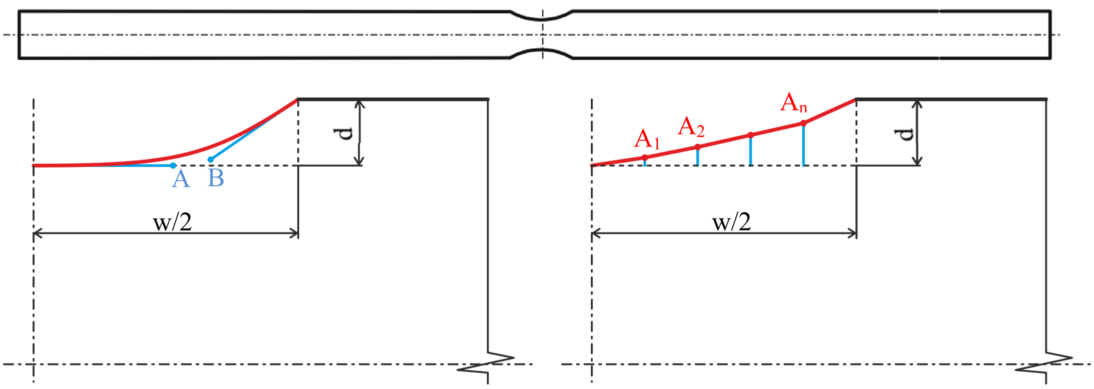

Fig. 1: *Top*: Bar with a undercut, *Bottom Left*: undercut modelled as a Bezier curve and described by *x*-coordinate of point A and *x* and *y*-coordinates of point B. *Bottom Right*: undercut modelled as polyline described by *y*-coordinates of points A_i.

The first method with only three parameters allows fast optimization, but results may be only inside the class of Bezier curves. The second method allows to describe any shape of undercut, but more parameters are necessary.

Optimization algorithm

Genetic algorithm was chosen as optimization method, because there is no possibility to explicit derivations formulation of the objective function. Objective function is stress concentration - maximal equivalent stress divided by nominal stress.

Implementation

FEM was implemented as a script in FreeFem++. Simple scripting language of FreeFem++ (similar to C++) allows fast and effective implementation of required functions.
Genetic algorithm was implemented in Matlab with FreeFem++ as external objective function and in FreeFem++ themselves. Matlab allows more operative modifications of genetic algorithm, FreeFem++ is faster.

Bar dimensions

A set of bar and undercut dimensions was used for testing – see Fig. 2 and Table 1. Undercut shape was optimized for each specimen using two undercut geometry descriptions (Bezier curve and polyline) and for two types of load – tension and bending.

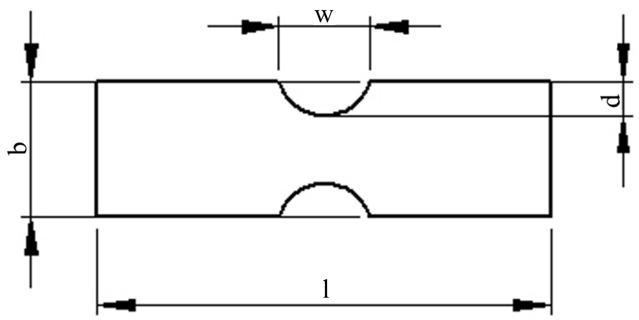

Fig. 2: Dimensions in general

Table 1: List of dimensions

Label of rod	l [mm]	b [mm]	w [mm]	d [mm]
w40d05	200	60	40	5
w40d10	200	60	40	10
w40d15	200	60	40	15
w50d05	200	60	50	5
w50d10	200	60	50	10
w50d15	200	60	50	15
w60d05	200	60	60	5
w60d10	200	60	60	10
w60d15	200	60	60	15

Results

Results for different undercut dimensions for bars loaded by tension are in Table 2. Results for bars loaded by bending are in Table 3.

A typical example is shown in Fig. 3. Bar is loaded by axial tension. Optimized undercuts has lower stress concentrations than reference circular undercut.

Table 2: Axially loaded bar: stress concentrations for circular and optimized undercuts

	d = 5 mm	d = 10 mm	d = 15 mm
	w = 40 mm		
Circular	1.3727	1.5310	1.4913
Bezier curve	1.2198	1.2972	1.2846
Polyline - 10 points	1.2926	1.3561	1.2887
	w = 50 mm		
Circular	1.2643	1.3869	1.3653
Bezier curve	1.1535	1.2035	1.1863
Polyline - 10 points	1.2365	1.3360	1.2115
	w = 60 mm		
Circular	1.1943	1.2837	1.2727
Bezier curve	1.1110	1.1441	1.1256
Polyline - 10 points	1.1656	1.2098	1.1297

Table 3: Bending loaded bar: stress concentrations for circular and optimized undercuts

	d = 5 mm	d = 10 mm	d = 15 mm
	w = 40 mm		
Circular	1.2168	1.2858	1.2615
Bezier curve	1.1130	1.1356	1.1041
Polyline - 10 points	1.1242	1.1443	1.0812
	w = 50 mm		
Circular	1.1463	1.2048	1.1984
Bezier curve	1.0718	1.0791	1.0607
Polyline - 10 points	1.0465	1.0799	1.0382
	w = 60 mm		
Circular	1.1053	1.1524	1.1536
Bezier curve	1.0441	1.0475	1.0368
Polyline - 10 points	10496	1.0526	1.0366

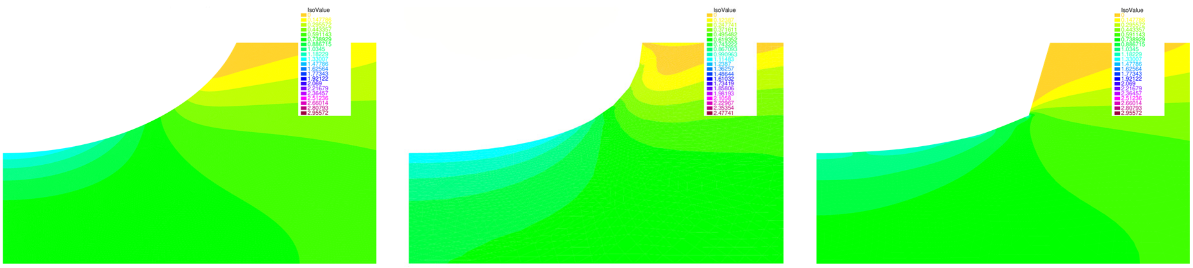

Fig. 3: Axially loaded bar. *Left*: Stress concentration in circular undercut (Max. = 1.478). *Center*: Stress concentration in undercut described by an optimized Bezier curve (Max. = 1.238). *Right*: Stress concentration in undercut described as an optimized polyline with 10 parameters (Max. = 1.270).

Conclusions

Genetic algorithm is useful and efficient for significant minimization of stress concentration by optimization undercut shape. It is efficient even by using Bezier curve, driven by only three parameters. This can be important for parts lifetime.

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References

[1] HECHT, Frédéric. New development in FreeFem++, Journal of numerical mathematics, 2012, vol. 20, no 3-4, p. 251-266.

[2] MOEZI, Seyed Alireza, ZAKERI, Ehsan, BAZARGAN-LARI, Yousef, ZARE, Amin. 2d Shape Optimization Via Genetic Algorithm. The Journal of Mathematics and Computer Science (JMCS), 2014. vol. 11, p. 209-217

[3] VALACKAITE, Laisvune, MACIUNAS, Darius, GLEBIENE, Elena. Shape Optimization of Two-dimensional Body Utilizing Genetic Algorithms. Conference of Informatics and Management Sciences, 2013, p. 449-452

[4] WOON, S.Y., QUERIN, O.M., STEVEN, G.P. Structural application of a shape optimization method based on a genetic algorithm. Structural and Multidisciplinary optimization. 2001, vol. 22, p. 57-64.