

Methods for Reducing the Stress Concentration in Cylindrical Specimens, at Axial Loading

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Abstract - The article presents specialized software methods for reducing stress concentration. Objects of study are cylindrical test specimens subjected to axial loading. Notching with different shapes and sizes on the specimens were formed to reduce the stresses in the endangered areas. The geometric parameters of notches identified through the specialized built-in modules to the ANSYS software. An analysis performed were to show the influence of stresses acting on the fatigue limit during different cycles. The results of the study were present in a graphical form.

Keywords - stress concentration, ANSYS, axial loading, notch.

I. INTRODUCTION

Stress concentrations are one of the main problems that arise in the construction of parts in mechanical engineering. Increasing stresses in local areas can lead to loss of performance or destruction of components. This is one of the main reasons why the optimization of the details in mechanical engineering is related to the reduction of the stress concentration and the increase of the fatigue limit.

The reduction of stress concentration is the subject of a number of specialized literature sources.

An optimization approach for stress reduction in stepped specimens subjected to axial loads is proposed in [1]. The purpose of optimization is to minimize the maximum value of stresses in the main shoulder fillet, thus increasing the fatigue limit. The objects of study are two stepped details: the first with the presence of only a basic shoulder fillet, and the second with the presence of a basic shoulder fillet and an additional cylindrical notch. The main approach presented by the authors consists in defining geometric parameters to be optimized to achieve a minimum value of the objective function. Specialized

software MATLAB and ANSYS were used for performing the optimization.

Elaboration of an additional cylindrical channel in the danger zones in order to reduce the stresses in a specific steel part is presented in [2]. The stress values are obtained by the finite element method using the specialized MARC/MENTAT software. The results show that due to the additional channel, the equivalent stresses decrease by about 10%.

Determining the best shape of shoulder fillet for stepped shafts and plates so that the maximum equivalent stress has the lowest possible value is a key goal in [3]. The optimization task is achieved with the help of a stochastic global search algorithm called "direct search simulated annealing". The optimized shape of the shoulder fillet is obtained with the help of spline curves passing through certain key points.

The analysis of the obtained results shows that the applied "direct search simulated annealing" method not only reduces the stress values, but also the optimized shoulder fillet are located on a smaller area.

A study of the stress concentration at a stepped shaft subjected to an axial load is described in [4]. Two types of shafts are considered: a stepped shaft with shoulder fillet of the foot and a shaft with shoulder fillet and a conical part of the foot. A simulation was realized with the help of the specialized ANSYS software. The analysis of the obtained results shows that:

- The coefficient of stress concentration at the step shaft is 30% higher than the coefficient known from the specialized literature.

- The stress concentration factor for a stepped shaft with a conical part is lower than that of a stepped shaft without a conical part by 5-10%.

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An approach to stress reduction in stepped shafts is presented in [5]. It is based on the methods CAO (Computer Aided Optimization) and FEM, which are used to optimize the geometric parameters, with the main shoulder fillet located between the steps of the shafts. Different variants of optimized shoulder fillet are proposed, in which the stress concentration is significantly lower compared to the shoulder fillets before optimization.

The main goal of the present work is to reduce the stress concentration in cylindrical test specimens subjected to axial loading with the help of the specialized ANSYS software.

II. MATERIALS AND METHODS

Objects of study are a cylindrical part with a centrally located U-shaped notch and a two-stage cylindrical part with a shoulder fillet. Both specimens are subjected to axial loading.

Schemes of the examined specimens are presented in Fig. 1, and the values of their geometrical parameters are given in Table I and Table II.

The simulations are realized with the help of the static module to the specialized ANSYS software. Initially, the specimens are subjected to axial loading and the values of the maximum stresses at different geometric ratios of the input parameters are determined.

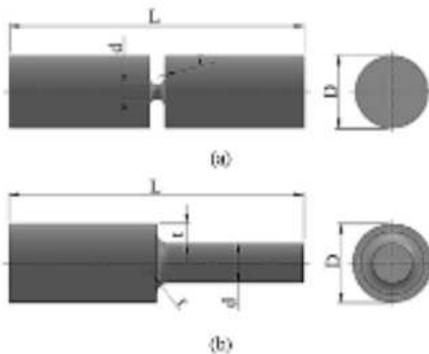


Fig. 1. Objects of study: (a) U-shaped specimen, (b) Specimen with shoulder fillet.

TABLE I.

Geometric dimensions of the specimen with a U-shaped notch.			
<i>D</i> , mm	<i>r</i> , mm	<i>L</i> , mm	<i>d</i> , mm
50	0,5	200	5
			15
			25
			35
			45

TABLE II.

Geometric dimensions of the specimen with the presence of shoulder fillet.				
<i>D</i> , mm	<i>d</i> , mm	<i>L</i> , mm	<i>t</i> , mm	<i>r</i> , mm
54	27	200	13.5	2,7
				4,05
				5,4
				6,75
				8,1

The coefficients of stress concentration are determined with the obtained results from the simulation. These coefficients are compared with those existing in the specialized literature [6]. In order to reduce the stresses in the endangered areas, additional notches with specific shapes and sizes were made on the specimens. With the help of the built-in ANSYS module OptiSLang, the geometrical parameters of the additional notches were identified, and a target function was set to minimize the maximum values of the stresses in the endangered areas.

With the help of the specialized module ANSYS nCodeDesignLife the influence of the additional notches on the fatigue limit in the examined samples was reported.

The stress concentration coefficients for both specimens are determined according to (1):

$$K_{tn} = \frac{\sigma_{max}}{\sigma_{nom}}; \sigma_{nom} = \frac{4P}{\pi d^2} \quad (1)$$

Where *P* is the axial force applied to the specimen.

III. RESULTS AND DISCUSSION

Fig. 2 shows the specific geometric shapes of the additional notches used in the simulations of the cylindrical specimen with a central U-notch.

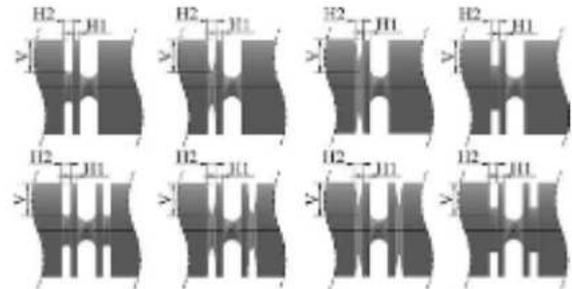


Fig. 2. Geometric shapes of the notches in the cylindrical specimen with a central U-notch.

Table III present the obtained values for the stresses and the concentration coefficient after the simulations, for different geometrical parameters *d*.

Table IV presents the values of the geometric parameters of the additional notches obtained after the optimization with OptiSLang, the maximum stresses at these parameters, as well as the stress concentration coefficient.

TABLE III.

Results from the simulation of a cylindrical specimen with a U-shaped notch.				
Parameter <i>d</i> , mm	Axial force <i>P</i> , N	σ_{nom} MPa	σ_{max} MPa	<i>K_{tn}</i> -
5	2000	101,859	272,34	2,673
15		11,317	49,592	4,381
25		4,0743	23,538	5,777
35		2,078	13,269	6,383
45		1,257	6,4164	5,102

TABLE IV.

Additional notches	H1, mm	H2, mm	V1, mm	σ max, MPa	K _{tn} -
<i>d=5 mm</i>					
U-notch	2,459	1,250	21,013	192,987	1,895
V-notch	1,622	2,222	20,988	237,063	2,327
Prismatic notch	4,636	1,873	15,249	243,613	2,392
Elliptical notch	2,471	1,471	18,485	200,065	1,964
Double-sided U-notch	3,426	1,452	18,620	180,924	1,776
Double-sided V-notch	2	2	15	241,069	2,367
Double-sided Prismatic notch	0,859	0,851	16,312	242,990	2,386
Double-sided Elliptical notch	4,018	4,305	19,591	205,433	2,017
<i>d=15 mm</i>					
U-notch	2,579	1,694	14,878	39,795	3,516
V-notch	3,274	2,087	11,087	46,535	4,112
Prismatic notch	1,461	1,809	17,572	34,879	3,082
Elliptical notch	3,870	0,731	9,972	39,113	3,456
Double-sided U-notch	2,825	0,500	11,838	39,690	3,507
Double-sided V-notch	2,015	1,983	15,085	38,002	3,358
Double-sided Prismatic notch	1,526	2,292	10,553	41,946	3,706
Double-sided Elliptical notch	1,441	4,714	9,500	37,414	3,306
<i>d=25 mm</i>					
U-notch	1,023	4,195	13,461	12,233	3,003
V-notch	1,705	2,232	8,321	21,514	5,281
Prismatic notch	2,484	1,844	12,381	15,069	3,699
Elliptical notch	4,979	4,439	12,398	15,848	3,890
Double-sided U-notch	1,070	4,998	12,982	9,801	2,406
Double-sided V-notch	3,013	3,709	11,021	15,535	3,813
Double-sided Prismatic notch	1,930	2,941	11,473	13,574	3,332
Double-sided Elliptical notch	3,241	4,059	3,545	16,128	3,959
<i>d=35 mm</i>					
U-notch	3,521	3,726	8,514	7,360	3,540
V-notch	3,770	2,858	6,402	10,968	5,276
Prismatic notch	1,839	1,421	7,501	8,738	4,203
Elliptical notch	2,930	2,720	5,945	9,674	4,653
Double-sided U-notch	3,848	5,000	7,781	5,314	2,556
Double-sided V-notch	3,254	2,756	5,730	9,189	4,420
Double-sided Prismatic notch	1,176	3,404	6,567	7,338	3,529
Double-sided Elliptical notch	2,014	4,877	7,455	7,260	3,492
<i>d=45 mm</i>					
U-notch	1,491	2,211	2,823	4,145	3,295
V-notch	3,293	1,878	1,506	5,653	4,494
Prismatic notch	1,532	3,285	2,420	4,443	3,532
Elliptical notch	1,436	3,577	3,086	3,918	3,115
Double-sided U-notch	1,762	4,675	2,653	2,973	2,363
Double-sided V-notch	2,864	2,626	1,265	4,937	3,925
Double-sided Prismatic notch	0,860	3,244	1,837	3,803	3,023
Double-sided Elliptical notch	1,686	3,405	2,841	3,640	2,893

Fig. 3 presents the stress concentration coefficients for all studied cases, as a function of the geometric ratio d/D .

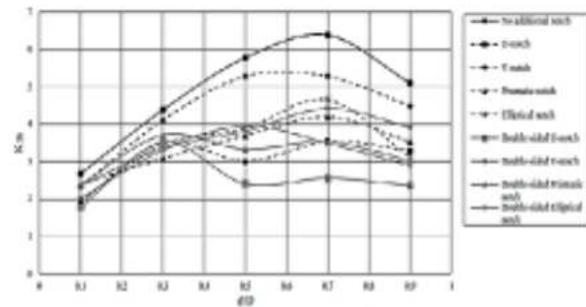


Fig. 3. Stress concentration coefficients for all studied cases, as a function of the geometric ratio d/D .

The obtained results show that the presence of additional notches significantly reduces the stresses in the endangered areas. The most significant influence in the present study is exerted by the double sided U-notch. With it, the stress concentration factor decreases by more than 30% compared to the results obtained without the presence of additional notches.

Table V presents the results for the maximum stresses and the stress concentration coefficient obtained in the simulation of the cylindrical stepped specimen, at different radius of fillet of the step.

TABLE V.

Results of the simulation of a cylindrical specimen with shoulder fillet.				
Parameter	Axial force	σ nom	σ max	K _{tn}
r , mm	P , N	MPa	MPa	-
2,7	100000	174,656	361,4	2,069
4,05			323,22	1,851
5,4			298,33	1,708
6,75			276,58	1,584
8,1			262,92	1,505

In Fig. 4 shows the notch shapes used in the simulation of the stepped cylindrical specimen.

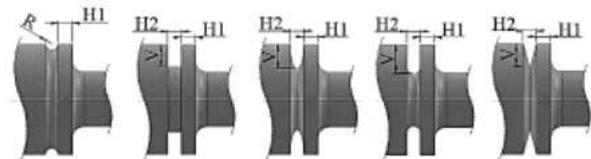


Fig. 4. Geometric parameters and shapes of the notches used in the simulation of the stepped specimen.

Table VI presents the values of the geometrical parameters of the notches, the maximum values of the stresses in the endangered areas, as well as the stress concentration coefficient obtained after the optimization with OptiSLang.

TABLE VI.

Additional notches	H1, mm	H2, mm	V1, mm	σ max, MPa	Ktn -
<i>r=2,7 mm</i>					
U-notch	7.166	3.242	10.471	310.743	1.779
V-notch	8.667	1.425	5.366	355.476	2.035
Prismatic notch	9.885	4.334	7.283	340.392	1.949
Elliptical notch	8.197	2.271	6.028	344.039	1.970
Semicircular notch	4.018	R=1.520 mm		351.458	2.012
<i>r=4,05 mm</i>					
U-notch	8.273	2.033	9.134	304.926	1.746
V-notch	7.234	3.586	1.161	317.822	1.820
Prismatic notch	7.803	3.696	4.451	318.712	1.825
Elliptical notch	6.007	4.542	9.140	306.172	1.753
Semicircular notch	9.939	R=9.987mm		303.824	1.740
<i>r=5,4 mm</i>					
U-notch	6.522	4.278	10.155	277.760	1.590
V-notch	6.779	2.655	0.977	293.532	1.681
Prismatic notch	5.863	4.897	6.061	291.457	1.669
Elliptical notch	6.886	4.209	7.947	288.098	1.650
Semicircular notch	7.434	R=9.999mm		282.777	1.619
<i>r=6,75 mm</i>					
U-notch	6.666	3.565	9.207	267.454	1.531
V-notch	5.830	0.777	0.500	273.844	1.568
Prismatic notch	4.521	1.652	5.893	274.309	1.571
Elliptical notch	8.967	4.704	6.965	272.547	1.560
Semicircular notch	2.853	R=9.908mm		265.375	1.519
<i>r=8,1 mm</i>					
U-notch	6.165	4.562	9.367	254.801	1.459
V-notch	4.350	1.151	5.123	260.696	1.493
Prismatic notch	6.135	1.976	3.389	260.875	1.494
Elliptical notch	1.144	1.709	5.418	261.017	1.494
Semicircular notch	5.802	R=10 mm		255.498	1.463

In Fig. 5 the stress concentration coefficients are presented in a graphical form as a function of the geometric ratio r/d .

The analysis shows that the best results are achieved in the presence of an additional U-shaped notch. With it, the stress concentration coefficients decrease by more than 10%.

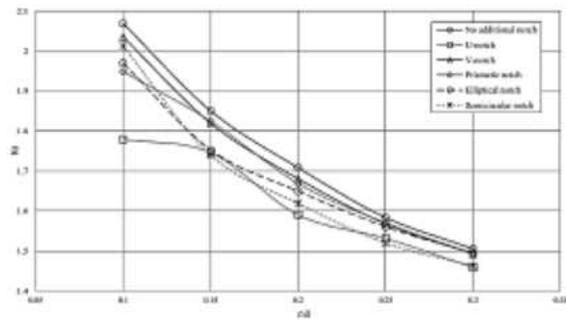


Fig. 5. Stress concentration coefficients for all studied cases, as a function of the geometric ratio r/d .

IV. CONCLUSIONS

The aim of the present study is to determine the influence of the additional notches on the stress concentration in the examined specimens with the help of specialized software. The results of the performed simulations show that with a certain shape, geometric dimensions and location on the studied specimen, the stresses in the endangered areas can be significantly reduced.

The obtained results can be used as a starting point for forthcoming experimental studies.

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