Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 100 (2015) 707 – 713
Procedia Engineering
www.elsevier.com/locate/procedia

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

Numerical Analysis of Stress Concentration Factors

Adis J. Muminovic*, Isad Saric, Nedzad Repcic

University of Sarajevo, Faculty of Mechanical Engineering, Vilsonovo setaliste No. 9, 71000 Sarajevo, Bosnia and Herzegovina

Abstract

Small computer software for analysis of stress concentration factors was developed at Faculty of Mechanical Engineering Sarajevo. Software name is AlfaK. Developing process of the software was presented in previous papers of same authors, in this paper testing of the software was done using numerical analysis. To test accuracy of AlfaK software, analysis of stress concentration factors was done numerically using CATIA V5 commercial software for characteristic geometrical changes in form. Obtained data from numerical analysis are used for comparison with results from AlfaK, and on that way, accuracy of AlfaK software is investigated.

Peer-review under responsibility of DAAAM International Vienna

Keywords: numerical analysis; stress; concentration; factors; software

1. Introduction

One of the problems for engineers, in developing countries, is to get access to expensive computer science packages. In most cases, engineering software packages such as CAD/CAM/CAE systems [1] are too expensive for small private companies or universities. On the other hand, in practice and in research, engineers are often faced with characteristic engineering problems which can be efficiently solved using computers. Solving them require to purchase expensive software package [2, 3].

One such problem is stress concentration caused by sudden change in form of machine elements [4]. In design process of machine elements analysis of stress concentration can be done using software like CATIA V5 [5], SolidWorks and NX, or using diagrams obtained experimentally for various geometric configurations involving abrupt changes in geometry [6]. These softwares are based on some of numerical method [5] (Finite element method

* Corresponding author. Tel.: +387 61 921 772.
E-mail address: adis.muminovic@mef.unsa.ba

Peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2015.01.423

FEM, Finite volume method FVM, etc). The above mentioned software are extremely expensive and they are not cost effective to purchase just for analysis of stress concentration. On the other hand, the analysis using experimentally obtained diagrams is relatively imprecise, because it means that engineer need to manually determine value from diagrams. From the above can be seen the need to find cheaper solution, but solution with appropriate accuracy. One solution, which is elaborated in [4] involves the use of Microsoft Office Excel.

This paper want to prove that with a good knowledge of programming languages like C# small computer software can be developed for analysis of stress concentration. This software will work independently of the others programs on the computer and it will allow simple and accurate analysis. More about AlfaK software can be found in [7]

2. Stress concentration

In the development of the basic stress equations for tension, compression, bending, and torsion, it was assumed that no geometric irregularities occurred in the member under consideration. But it is quite difficult to design a machine without permitting some changes in the cross sections of the members. Rotating shaft must have shoulders designed on them so that the bearings can be properly seated and so that they will take thrust loads, also the shafts must have key slots machined into them for securing pulleys and gears, etc. [8]

Abrupt changes in geometry can give rise to stress values that are larger than would be expected. This can be a source of difficulty for designers. Consider, for example, the state of stress in the tension member of two widths illustrated in Fig. 1 [4]. Near each end of the bar the internal force is uniformly distributed over the cross sections. The nominal stress in the right part can be found by dividing the total load by the smaller cross-sectional area, the stress in the left part can be found by dividing by the larger area. However, in the region where the width is changing, a redistribution of the force within the bar must take place. In this part, the load is no longer uniform at all points on the cross section, but the material in the neighborhood of points B in Fig. 1 is stressed considerably higher than the average value. The stress situation is thus more complicated, and the elementary equation (1) is no longer valid [7].

$$\sigma_{nominal} = \frac{P}{A} \quad (1)$$

The maximum stress occurs at some point on the fillet, as at B, and is directed parallel to the boundary at that point.

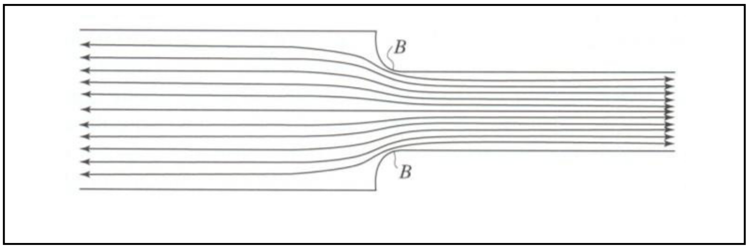


Fig. 1. Stress concentracion caused by a sudden change in cross section.

The stress distribution along the cut surface is practically uniform until the neighbothood od the fillet is reached, where it suddenly increases. This irregularity in the stress distribution caused by changes of form is called stress concentration. It occurs for all kinds of stress, axial, bending, or shear in the presence of fillets, holes, notches, keywayes, splines, tool marks, or accidental scratches. Inclusions and flaws in the material or on the surface also serve as stress raisers. The maximum value of the stress at such points is found by multiplying the nominal stress as given by the elementary equation by stress concentration faktor K, or K_t [4].

$$K_t = \frac{\sigma_{actual}}{\sigma_{nominal}} \quad (2)$$

Where is σ_{actual} - highest value of actual stress on fillet, hole, etc., $\sigma_{nominal}$ - nominal stress as given by (1). The subscript t in K_t means that this stress concentration factor depends for its value only on the geometry of the part.

This is why it is called a theoretical stress concentracion factor. It can be noticed that as geometric changes are made gradually, the effect of stress concentration factors is decreased. Sometimes the designer can specify the removal of material to secure a more gradual transition in size.

2.1. Stress concentration factors

The analysis of geometric shapes to determine stress concentration factor is a difficult problem, and not many solutions can be found. Most stress concentration factors are found by using experimental techniques. Though the finite element method has been used, the fact that the elements are indeed finite prevents finding the true maximum stress. Experimental approaches generally used include photoelasticity, grid methods, brittle-coating methods and electrical strain-gauge methods. Stress concentration factors have been determined for a wide variety of geometric shapes and types of loading. The best known summary of results for various geometric shapes is the work by Peterson and is based on results from photoelastic testing done prior to 1951 [4]. For example, the results for a shaft with a shoulder fillet in axial tension are given in Fig. 2.

More recently, researchers have developed mathematical models to approximate this classical data. Some of the best examples of these approximating models are documented by Norton, Pikley, and Young.

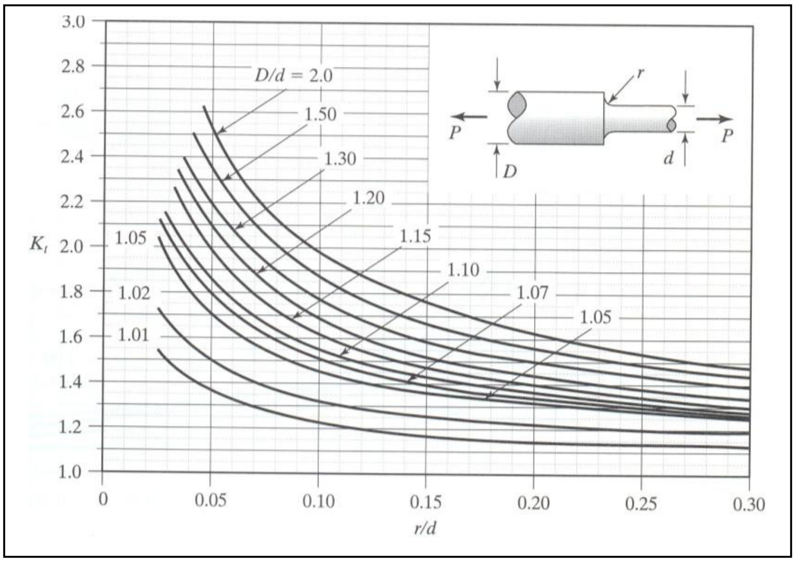


Fig. 2. Stress concentration factor for a shaft with a shoulder fillet in axial tension.

3. Analysis of stress concentration factor using AlfaK software

AlfaK software is user friendly and it is designed to be easy to use. It has only two windows (forms), welcome window and main software window. Main software window has two parts. First part (Fig. 3) represent the part where user can choose geometric shape for analysis. As it can be seen AlfaK software can be used for analysis of stress concentration factor for six characteristic cases of changes in form.

Second part of main window enable user to enter geometrical data, data for load (axial tension, bending and torsion are available), also this part of the window shows results of analysis.

Fig. 3. shows analysis of stress concentration factor for shaft with shoulder fillet from *D* to *d* and with load in

form of force of $2000\ N$. It can be seen that value for K_t is 1.678 and values for stresses are: $s_{nominal} = 6.366\ MPa$, $s_{actual} = 10.681\ MPa$.

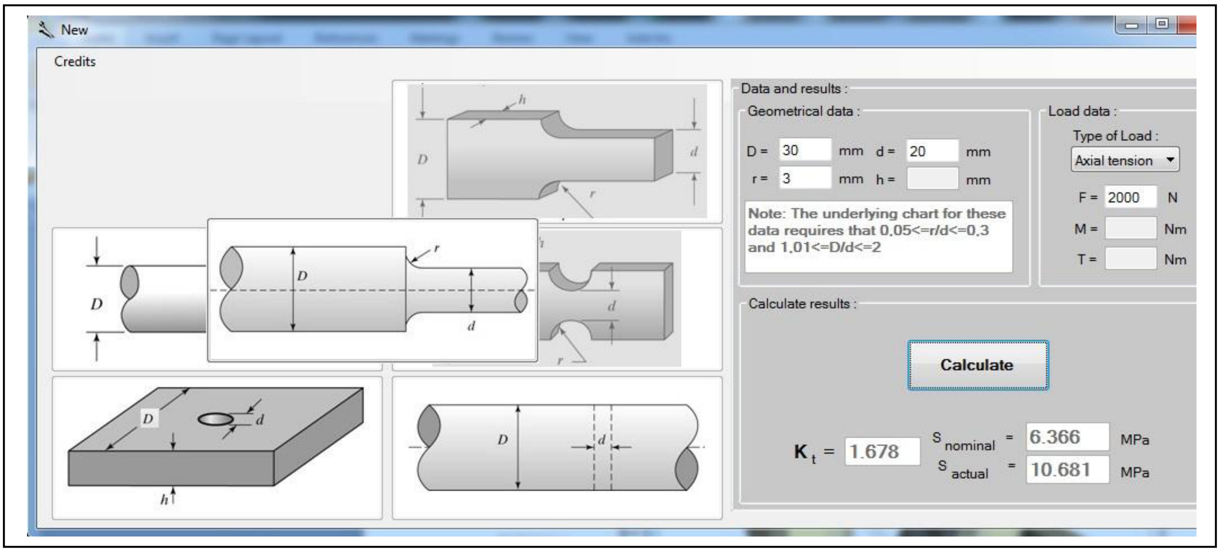


Fig. 3. Main „AlfaK“ form.

4. Numerical analysis of stress concentration factors

In order to verify the accuracy of the AlfaK software, analysis of stress concentration factor was performed using numerical analysis in CATIA V5 commercial software. Analysis steps are different for different types of loads. Precise steps for numerical analysis can be found in [3]. Axial tension, bending and torsion are available in AlfaK software. In this paper, numerical analysis is done for axial tension and bending.

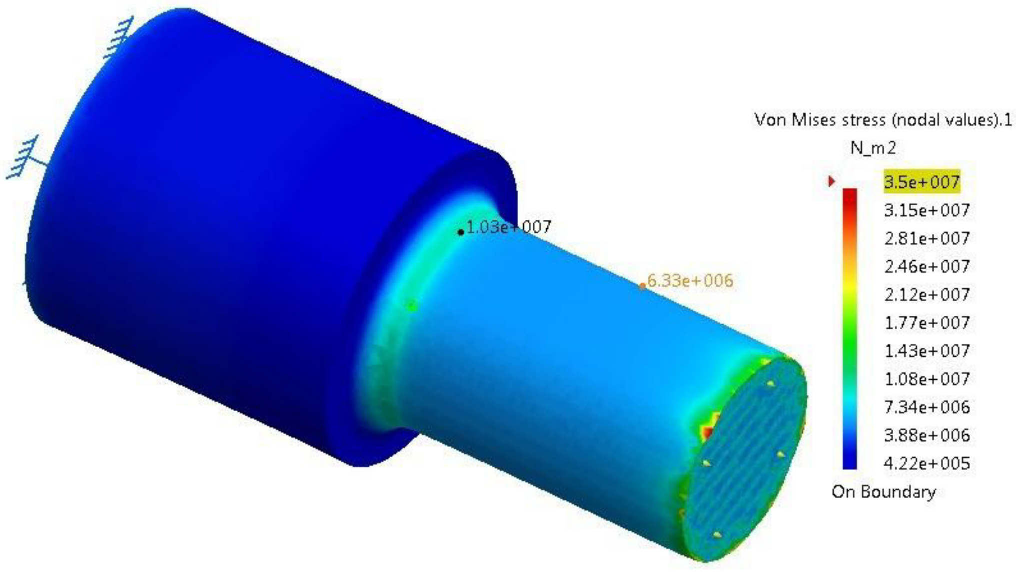


Fig. 4. Numerical analysis of stress concentration factor for shaft with shoulder with axial tension load.

Fig. 4 and 5 shows results of numerical analysis for axial tension and bending for shaft with shoulder fillet from D to d and with same data as is shown on Fig. 3, from the pictures it can be seen that actual stress is on the shoulder where diameter becoming smaller. Stress on the end face of the part can be ignored, it is big because this face is connected to the support and virtual part, in this case axial tension force is applied to this face. Taking values for nominal and actual stress from the points shown on the figures and using equation (2) stress concentration factor can be calculated.

For example, for axial tension (Fig. 4) values for stresses are: $s_{nominal} = 6.330\ MPa$, $s_{actual} = 10.300\ MPa$, using this values, K_t can be calculated:

$$K_t = \frac{\sigma_{actual}}{\sigma_{nominal}} = \frac{10.300}{6.330} = 1.627 \tag{3}$$

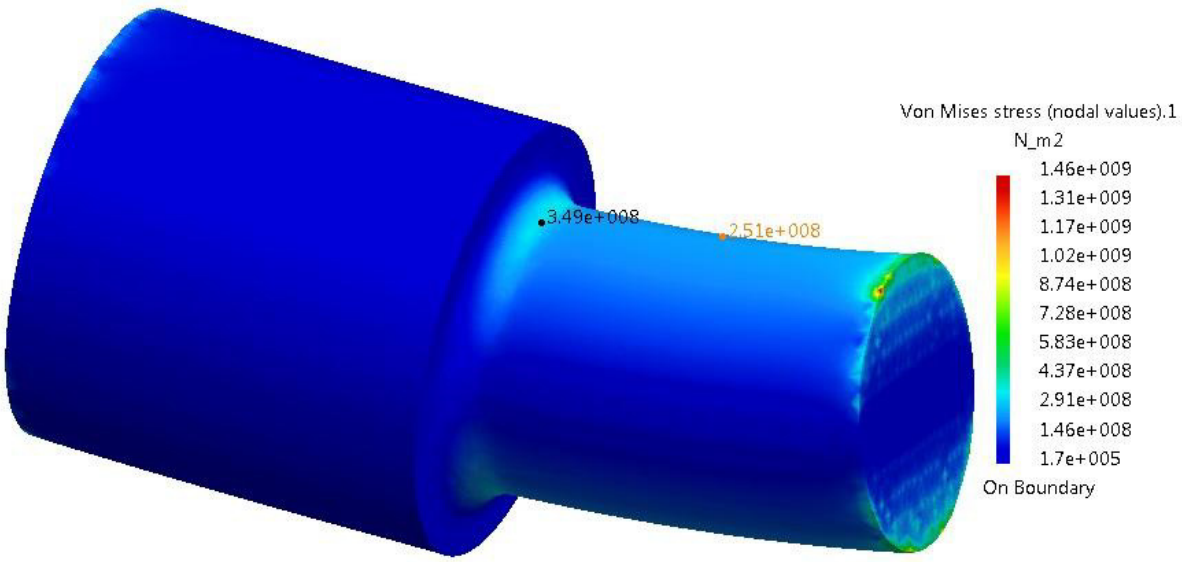


Fig. 5. Numerical analysis of stress concentration factor for shaft with shoulder with bending load.

For bending (Fig. 5) values for stresses are: $s_{nominal} = 251\ MPa$, $s_{actual} = 349\ MPa$, using this values, K_t can be calculated:

$$K_t = \frac{\sigma_{actual}}{\sigma_{nominal}} = \frac{349}{251} = 1.390 \tag{4}$$

Using this procedure concentration factor K_t can be found numerically for all types of geometry and all types of loads. Results for numerical analysis for different type of geometry and different type of loads are shown in Tab. 2. Results are calculated for input data from Tab. 1. It is important to notice that this data can be compared to the experimental results which can be found in [4].

5. Results

Table 1. Input data.

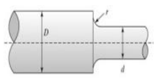
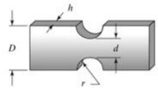
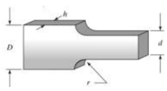
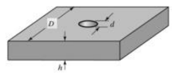
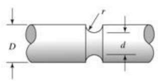
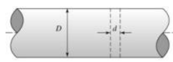
No.	Type of geometry	Geometric data (mm)	Stress data		No.	Type of geometry	Geometric data (mm)	Stress data	
			Axial tension F (N)	Bending M (Nm)				Axial tension F (N)	Bending M (Nm)
1.		D = 30 d = 20 r = 3	2000	200	4.		D = 30 d = 20 r = 3 h = 5	2000	200
2.		D = 30 d = 20 r = 3 h = 5	2000	200	5.		D = 30 d = 5 h = 5	2000	200
3.		D = 30 d = 20 r = 3	2000	200	6.		D = 30 d = 5	---	200

Table 2. Results.

No.	Type of load	Stress concentration factor		Nominal stress (MPa)		Maximal stress (MPa)	
		AlfaK	Numerical Anlysis	AlfaK	Numerical Anlysis	AlfaK	Numerical Anlysis
1.	Axial tension	1.678	1.627	6.330	6.366	10.681	10.300
	Bending	1.507	1.390	254.64	251	383.778	349
2.	Axial tension	1.864	1.837	20.000	20.000	37.276	37.734
	Bending	1.580	1.52	600.000	600.200	948.264	973.327
3.	Axial tension	1.983	2.052	6.366	6.366	12.626	12.809
	Bending	1.714	1.64	254.448	254.647	436.462	441.936
4.	Axial tension	2.252	2.298	20.00	20.00	45.034	45.351
	Bending	1.821	1.8	600.0	600.0	1092.52	1111.51
5.	Axial tension	2.579	2.459	16.00	16.12	41.270	40.640
	Bending	1.828	1.976	1920	1920	3509,78	3771,86
6.	Axial tension	2,091	2,22	105,323	105,123	219,979	221,50
	Bending	2,76	2,75	43,942	43,948	121,577	121,69

In Tab. 2. very good fit of data, between numerical analysis and AlfaK software, can be noticed. From this results it can be seen that AlfaK software has an expected accuracy.

Conclusion

This paper presents results of stress concentration factor analysis using developed software and numerical procedure. The goal of the paper is to prove that, with good knowledge of computer languages (like C#), small software, for specific engineering problems, can be developed. On this way engineers can avoid buying expensive computers software packages. In Tab. 2. very good fit of data, between two types of analysis, can be noticed. From this results it can be seen that AlfaK software has an expected accuracy. AlfaK software enables analysis of stress concentration factor only for six characteristic cases of geometry. In practice, engineers can encounter much more cases of different types of geometry, because of that, AlfaK software have a lot of space to future development and research. Also, from practical point of view it would be good to take into account different types of materials, and make the analysis of stress concentration factor for that cases using experimental technique.

References

[1] A Muminovic, I. Saric, and E. Mesic, Computer-Aided Design (CAD), Sarajevo: Faculty of Mechanical Engineering Sarajevo, 2012. ISBN 978-9958-601-41-5, COBISS.BH-ID 19995654.
[2] N. Repcic, I. Saric, and A.J. Muminovic, "Software for Calculation and Analysis of ISO System of Tolerances, Deviations and Fits", Annals of DAAAM for 2012 & Proceedings of the 23rd International DAAAM Symposium, B. Katalinic, Ed. Vienna: DAAAM International, 2012, pp. 0195-0198, ISBN 978-3-901509-91-9, ISSN 2304-1382.
[3] A.J. Muminovic, I. Saric, and N. Repcic, "Software for Deformity and Stress Condition of 2D Truss Beams Analysis", Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium, B. Katalinic, Ed. Vienna: DAAAM International, 2011, pp. 1225-1226, ISBN 978-3-901509-83-4, ISSN 1726-9679.
[4] M.F. Spotts, T.E. Shoup, and L.E. Hornberger, Design of Machine Elements, 8th ed., New Jersey: Prentice Hall, Upper Saddle River, 2004. ISBN 0-13-126955-0.
[5] 3N.G. Zamani, CATIA V5 FEA Tutorials, Relase 19, University of Windsor, Schroff Development Corporation, 2010. ISBN: 978-1-58503-586-1.
[6] T. A. Enab, "Stress concentration analysis in functionally graded plates with elliptic holes under biaxial loadings" Ain Shams Engineering Journal, Volume 5, Issue 3, September 2014, Pages 839–850
[7] A.J. Muminovic, I. Saric, and N. Repcic, Analysis of Stress Concentration Factors Using Different Computer Software Solutions, Procedia Engineering, Volume 69, 2014, Pages 609–615, 24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013.
[8] J.E. Shigley, C.R. Mischke, and R.G. Budynas, Mechanical Engineering Design, 7th ed., New York: McGraw-Hill, 2004. ISBN 007-252036-1.