EAN 2014
52nd conference on experimental stress analysis

Wiles of Using Hollow Specimens for Fatigue Tests

PAPUGA Jan[1,a] and VARGAS Miguel Aguilar[1,b]

[1]CTU in Prague, Faculty of Mechanical Engineering, Department of Mechanics. Technická 4, 166 07 Prague 6, Czech Republic

[a]papuga@pragtic.com, [b]miguel.vargasaguilar@fs.cvut.cz

Keywords: Fatigue specimens, out-of-phase loading, relative stress gradient.

Abstract. The paper reports an issue found in using the hollow specimens claimed usually as unnotched. If the goal is to test them under multiaxial loading, the target is to reduce the shear stress gradient by making them thin-walled. Anyhow, the finding describe here shows, that this attempt induces an issue unknown previously to authors – the maximum stress in tension loading is found on inner surface of the tube. The individual effects concerning material and geometry are described.

Introduction

FADOFF consortium runs a large-scale testing campaign focusing on the fatigue behavior of tubular and notched bar specimens fabricated from 2124-T851 aluminum alloy under load-controlled loading. An in advance unexpected phenomenon encountered during the specimen preparation and testing affected the output of the campaign. It was found when analyzing a stress distribution caused by tensile loading in a common hollow fatigue specimen, with a bigger diameter at grips, and transition fillet leading to the minimum diameter in the central part (see Fig. 1). The higher stress was expected being found on the outer surface due to the radius R80, but the reality differed. The location of the maximum stress switched to the inner surface.

The same roughness was prescribed for inner and outer surface, and the exact location of the critical locality thus does not matter for the most of the experiments. Anyhow, an important output of our tests had to be the comparison with the same stress ratio between axial and torsion stress components, while the harmonic signals of related force and torque signals should be either with 90 degrees shift or proportional (0 degrees shift).

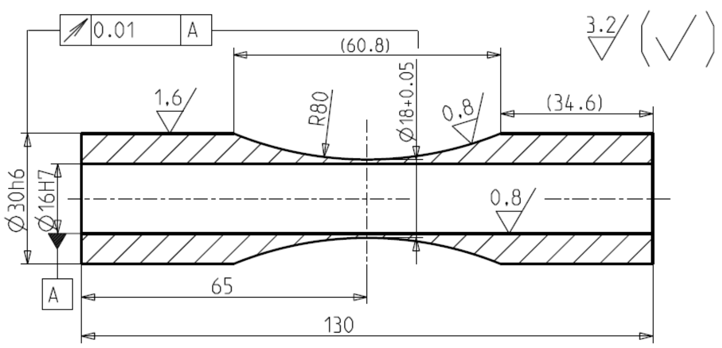

Fig. 1. The drawing of the original specimen.

If the maximum stress locality for tension loading is found on the inner surface, the torsion stress maximum is located on the outer surface. In the case of the in-phase loading, the final load combination decides, which location is the critical one. When the out-of-phase loading is applied, the outer surface is critical at one moment (maximum of torque), but inner surface at another moment (maximum of axial force).

Building FE-models

The preparation of the models was simplified by the use of previously prepared ANSYS APDL [1] macros [2]. The macros were prepared in order to simplify next benchmark tests during FADOFF benchmark campaign evaluating the multiaxial and notch effect on the fatigue life. The macros cover the most often kinds of notches (U-notch, V-notch, fillet, hole) on the typical specimen configuration (bar, hollow tube, plate), including also the specimens used as unnotched, as the one depicted in Fig. 1.

The input of the macros is based on a simple parametrization of the geometric parameters. Using the macros, the user can prepare a complete model, apply the boundary conditions and solve the task by running two commands only. The macros use PLANE83 as element type, which is a 8-node axisymmetric-harmonic structural solid element. The dedication of the element type to the harmonic analysis is essential, because it allows to obtain the solution on axisymmetric model even for cases, where the loading is not axisymmetric.

Effect of the Material Parameters

Because Poisson's ratio affects the straining in the direction perpendicular to loading, it was first tested, what will be the impact of changing both basic material parameters used in FEA – Poisson's ratio ν and Young's modulus E. The inputs and outputs describing the relative difference in stresses on inner and outer surfaces for various typical materials can be found in Table 1, and is also graphically provided in Fig. 2. No effect of Young's modulus was found as can be seen in Fig. 2, when the values at Poisson's ratio 0.31 are compared. In all cases by 1 mm wall thickness, the maximum axial stress is located on inner surface.

Table 1. Summary of elastic material properties for 6 isotropic materials and the results.

Material	E [GPa]	ν [-]	$(\sigma_{y,inner}-\sigma_{y,outer})/\sigma_{y,outer}$	Material	E [GPa]	ν [-]	$(\sigma_{y,inner}-\sigma_{y,outer})/\sigma_{y,outer}$
Al alloy	72.4	0.31	1.71%	Austenitic steel	193	0.28	1.33%
Cu	110	0.31	1.99%	Ti	117	0.31	1.71%
Structural steel	200	0.33	1.99%	W	400	0.27	1.20%

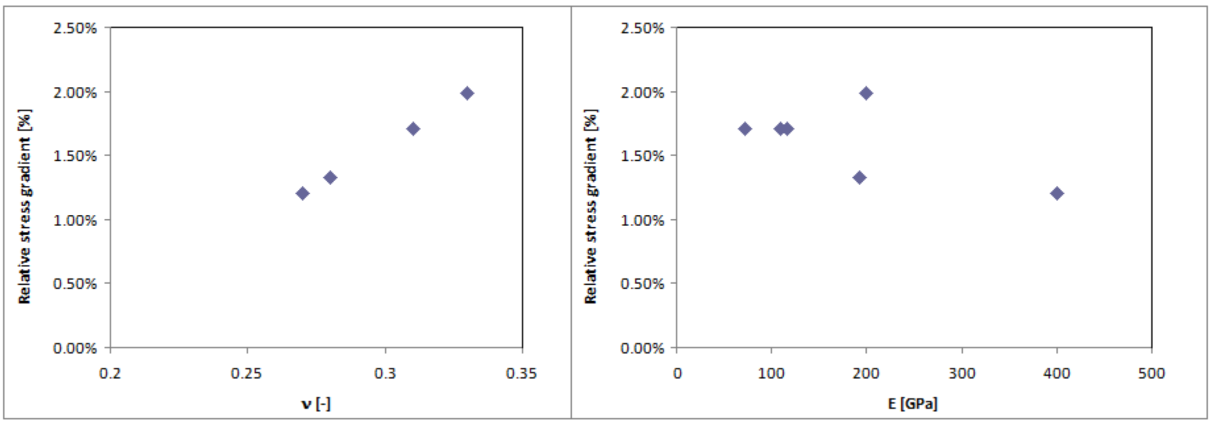

Fig. 2. Correlation of elastic constants with magnitude of the stress gradient found for samples of 1 mm thickness (see its shape on Fig. 1).

Effect of the Wall Thickness

In addition to material parameters, the effect of the wall thickness in the critical cross-section was analyzed. Other parameters than the outer diameter were kept fixed as shown in Fig. 1. A strong dependency as shown in Table 2 was found. Anyhow, it is obvious that wall thickness bigger than 2 mm is necessary to reach the maximum stress at the outer diameter for tension load case.

Table 2: Summary of elastic material properties for 6 isotropic materials and the resulting relative stress gradient.

Relative stress gradient $(\sigma_{y,inner}-\sigma_{y,outer})/\sigma_{y,outer}$	Wall thickness			
	1 mm	2 mm	3 mm	4 mm
Al alloy	1.71%	0.21%	-1.30%	-2.83%
Structural steel	1.99%	0.45%	-1.09%	-2.66%
Wolfram	1.20%	-0.24%	-1.69%	-3.17%

Effect of the Ratio of Thicknesses in the Active Part and in Clamps

A study was realized, whether the effect found in our case described in Fig. 1 could be caused by a constraint induced by very different thicknesses in the active part (1 mm) and in the clamped part (7 mm). In the case of 1 mm thickness in the active part, the diameter in clamps was changed to 24, 28, 36 mm. No effect on relative stress gradient was observed.

Effect of the Fillet Radius

The last variable of the geometry that could affect the stress distribution concerns the fillet radius (80 mm in Fig. 1). The test realized on the specimen depicted in Fig. 1 shows the pronounced effect of this parameter. Anyhow, the fillet radius should be so small, that the final notch factor would not allow the experimenters to claim the specimen to be unnotched.

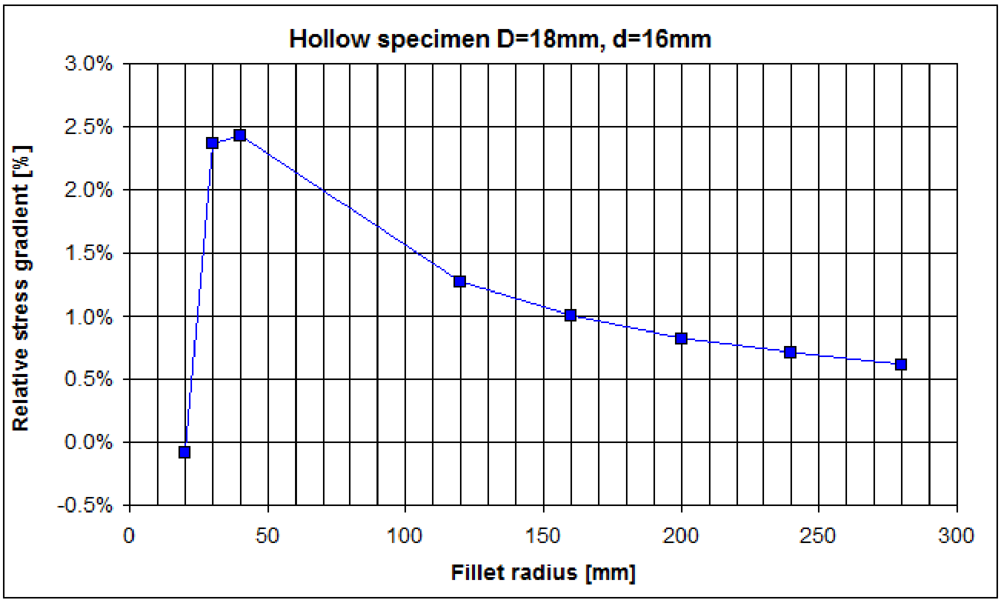

Fig. 3. Effect of the fillet radius on the relative stress gradient, for the specimen diameter parameters as stated in Fig. 1.

Conclusion

When hollow specimens are used for fatigue testing, great care should be dedicated also to the inner surface of the tube. Based on Poisson's ratio, wall thickness and fillet radius values, the maximum stress can switch from outer surface to the inner surface for the tension load case. In case of out-of-phase tension-torsion loading, the location of the maximum stress can switch between minimum and maximum diameter during the loading cycle. The most often used geometry with 1 mm thickness does not allow the experimenters to get the location of the maximum stress in tension to the outer surface. A bigger thickness (3 mm) is necessary in such cases.

Acknowledgement

The works described here were realized thanks to the TACR support of TA01011274 project.

References

[1] ANSYS® Release 14.5, Help System, ANSYS Parametric Design Language Guide, ANSYS, Inc.

[2] M. Pliš, Set of APDL macros for automated preparation of fatigue specimens [FAD/12/002 Technical Report, ver. B], Evektor spol. s r.o., Kunovice 2013.

[3] M. Vargas, F. Fojtík, J. Papuga, A. Hodr, Summary of experiments realized within FADOFF project [FAD/12/005 Technical Report], CTU in Prague and VŠB TU Ostrava, Prague, 2012.