CRUCIFORM SPECIMENS FOR TESTING OF ENGINEERING MATERIALS

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Abstract: The paper presents selected cruciform specimens recommended for static and fatigue tests. Guidelines for cruciform specimens designing and optimization are presented. Numerical data of FEA analysis of Kelly's cruciform specimen in 3D coordinate systems are shown. Various types of cruciform testing machines and their advantages and disadvantages are discussed. The project of the cruciform specimen for examination of material behaviour under static and cyclic loading types is proposed.

Key words: cruciform specimen, biaxial stress state, specimen optimization, static test, fatigue test, FEA, effective stress

1. INTRODUCTION

Besides of the thin-walled tubular specimens applying in complex loading investigations of different kinds of materials also cruciform specimens enable examination of materials giving additional options for their characterization. A measurement section of this type of specimens is usually in a shape of circle (Ogata and Takahashi, 1994; Hatanaka, 1997), rectangular or square (Kelly, 1976; Makinde et al., 1992). Contrary to the typical specimens such as cylindrical or tubular, the cruciform ones have four griping arms used to mount them in a cruciform testing machine. Their geometry creates loading nonuniformity in the specimen measurement section. It is possible to reduce it by application of technological grooves, (Kelly, 1976; Bartolotta et al., 1997; Makinde et al., 1993). Such approach is mainly applied for specimens manufactured from thin sheets.

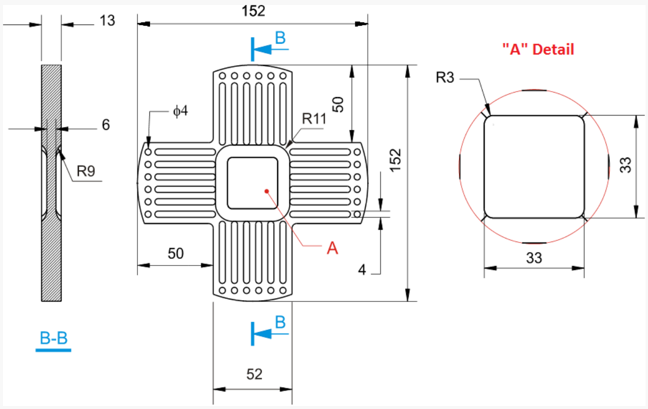

Fig. 1. Kelly's specimen for static tests (Kelly, 1976)

Various designs of cruciform specimen have been elaborated up to now. Measurement bases for examination of material behaviour under static loading (Fig. 1) are usually larger than those used for determination of material properties under cyclic loading, Fig. 2.

In order to achieve reasonable results a shape of the cruciform specimens should be optimized. This issue was considered by a lot of research groups (Demmerle and Boehler, 1993; Makinde, 1992). First investigations in this area have been done by Boehler. It has been shown numerically that even 70% improvement of stress uniformity can be achieved by proper design of the specimen.

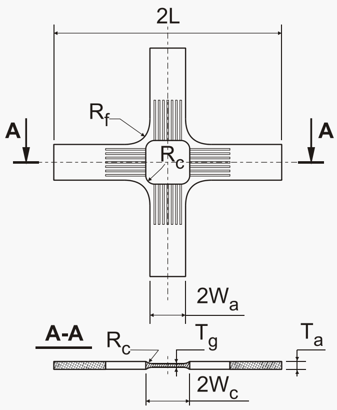

Fig. 2. Specimen for fatigue test (Makinde et al., 1992)

Boehler proposed standard deviation for determination of differences between stress state appeared in measurement zone and its nominal values. Moreover, equation for calculation of stress concentration level appeared between measurement and gripping zones was proposed:

$$K = \left(\frac{\sigma_{e\max}}{\sigma_e(a) - 1} \right) P \, . \tag{1}$$

Makinde (1992) proposed the following relationships in order to design effectively a cruciform specimen:

$$L \geq 2W_a;\ 4 \leq T_a/T_g \leq 6;\ R_f = \frac{2}{3}W_a;\ R_c = \frac{23}{25}W_a;$$
$$R_t = \frac{4}{3}W_a; \qquad (2)$$

where: W_a – gripping arm width, T_a, T_g – thickness gripping zone and measuring section, respectively. Cruciform specimens are mounted by means of pins (Instron, 2016), chain (Kelly, 1976), knife bearing (Demmerle and Boehler, 1993) or directly in grips of testing machine (Bartolotta, 1997; Ogata and Takahashi, 1997). Cruciform testing machines are designed to have two variants of actuators i.e. rectangular (Lemmer et al., 2015; MTS, 2016) and 45° rotated (Instron, 2016). Application of the twisting moment is considered to be additional type of loading used in this type of testing machines, (MTS, 2016).

2. RESULTS

Distribution of stress uniformity (Figs. 3, 4) in a measurment part of the Kelly's specimen was determined using FEA method. Material was modelled to have linear stress-strain curve. The specimen body was divided applying 3D eight-nodes rectangular Hex 8 elements. MultiPoint Constraint conception was employed to apply movement in selected direction for simulation of cruciform loading.

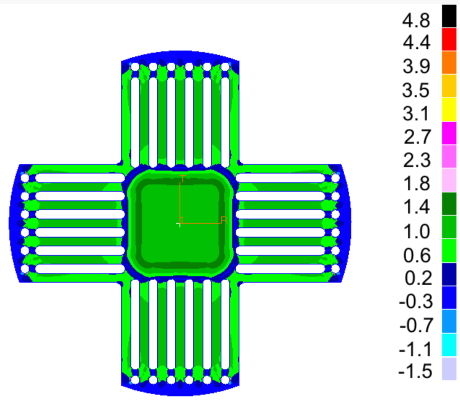

Fig. 3. Radial stress distribution for the specimen presented in Fig. 1

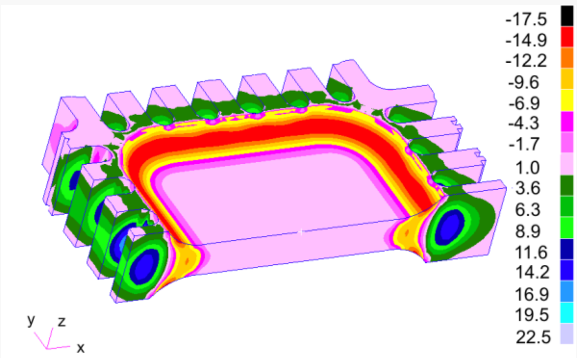

Fig. 4. Distribution of σ_{zz} along the cross section of the specimen presented in Fig. 1

FEA results indicated almost 80% stress uniformity of the measurement part of the specimen taking into account distribution of radial stress component (Fig. 3). Similar effect can be also observed for axial stress component in 0z direction perpendicular to 0xy plane (Fig. 4). Disturbances of the stress state were only noticed at radial transition between griping arm and testing zone, Fig. 4.

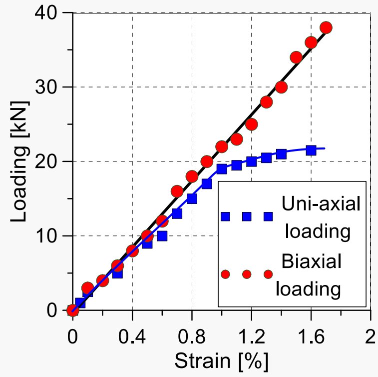

Fig. 5. An influence of loading type on material behaviour (Shimamoto et al. 2003)

An identification of the effect related to testing under simple and complex stress states on cruciform specimens is illustrated in Fig. 5. It justifies necessity of material characterization under biaxial loading.

3. SUMMARY

The paper summarizes current achievements in the area of cruciform specimen designing. It is emphasised that tests carrying out on cruciform systems enable supplementary knowledge on mechanical properties to be obtained with respect to investigation on thin-walled tubular specimens.

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