1 Introduction

The solutions of plane theory of elasticity, are still popular and serve as a basis for many engineering design procedures, standards and failure assessment codes due to their convenience and relative simplicity. In terms of numerical costs, two-dimensional models, based on plane stress or plane strain assumption, are much more computationally efficient, much easier to build and verify in comparison with the corresponding three-dimensional counterparts. Furthermore, three-dimensional equations of elasticity are not very amenable to analytical techniques.

In order to evaluate the dominant state of stress for dealing with crack problems, a simple empirical rule as being thin and thick enough is proposed for plane stress and plane strain condition respectively. On the other hand, until now there is no generally accepted criterion for identifying what thicknesses correspond to plane-stress or to plane-strain conditions.

A large number of publications in the recent literature [1–8] address the above mentioned issue. By considering some realistic crack shapes in three-dimensional (3D) finite element (FE) models and using automatic crack growth techniques, the extent of surface regions in cracked bodies under tension loading condition was investigated in ref. [9]. Based on their findings, the extent of both regions (extent of surface and near surface) was related to the elastic stress concentration factor (SCF) of the corresponding uncracked geometries and a linear relationship was found. In ref. [10] by using a user defined material model based on the analyt-
ical approach, a simulation of brittle fracture in isotropic materials in 3D space was performed. In another work, some detailed 3D FE models of spot welds for different ratio values of sheet metal thickness and spot-weld diameter are investigated [11]. The aim was to study the mechanical behavior of spot welds under tensile-shear and symmetric coach-peel loading conditions. In ref. [12] by using 3D FE models, a modified equation for the SCF of an isotropic plate with a centered countersunk hole is proposed. Factorial and multi parameter fit analyses were conducted on the FE results to formulate a general parametric equation for the maximum SCF in terms of the four dimensionless geometric parameters. The advantage of proposed equations is demonstrated by comparing them with other methods in the literature.

An extensive review [3] of some recent analytical, numerical and experimental results is presented to investigate the effect of plate thickness on elastic deformation as well as quasi-brittle fracture of plate components. For a plate under the in-plane loading condition, two basic assumption for the state of stress in the frame of plane theories of elasticity, namely plane stress (zero transverse stress) and plane strain (zero transverse strain), are commonly used [13].

In dealing with periodic blunt notches and by using the strain energy density (SED) approach, plane strain condition is assumed to evaluate the SCFs of a number of flat plates and round bars with periodic U- and V-notches. Tension, bending and torsion loading conditions have been considered [14].

Bolts, screws and rotary shouldered connections, as examples of periodic notched components, play an important role in the performance of the machinery. There are numerous studies in the literature addressing the fatigue life of the bolts. Among the others, the effect of thread pitch on the fatigue life of bolts is studied experimentally in ref. [15]. In another study, the effect of nut geometry, curved spring washer and a sealing material on the fatigue life of M12 and M16 ISO bolts was investigated in ref. [16]. An innovative technique is proposed in refs. [17,18] with the aim of increasing the fatigue strength of rotary shouldered connections used in oil drilling industry.

In the presence of sharp periodic notches and by means of SED, the plane theory of elasticity is assumed to study the variability of the notch stress intensity factors (NSIFs) of periodic sharp notches in ref. [19]. A new model of depth reduction factor for different ratios of relative depth of the notch is proposed to match the results from the SED approach. In the case of shallow notches, the results are compared with some semi-analytical solutions provided in ref. [20]. In addition, based on the best fit of numerical data from the SED approach, some polynomials for non-dimensional NSIFs in the case of intermediate and deep notches are presented. In another work by the authors [21], some very simple expressions were derived for the direct evaluation of the SED and the NSIF of plates with infinite width as a function of the notch spacing in the case of narrow sharp notches.

In this study, for the first time, an attempt is made to investigate the thickness effect on the location of maximum stress and notch stress intensity factor (NSIF) of corresponding blunt and sharp periodic notches in three-dimensional plates weakened by periodic blunt and sharp notches. A number of sophisticated three-dimensional finite element models are built with this aim.

In addition, different number of periodic notches as well as different notch opening angles are examined.

2 Finite element model and SED calculation

In the present paper, both types of 3D blunt and sharp periodic notches are analyzed by means of the FE method within ANSYS software. Six models with different geometrical configurations (summarized in Table 1) have been considered. A total of about 100 geometrical configurations are investigated.

The geometrical parameters, namely, notch depth ($t$), notch radius ($r$), pitch of the notch ($p$), notch opening angle ($2\alpha$), plate thickness ($H$), width of the plate ($W$) and plate length ($L$) and boundary conditions are shown in Figure 1, in which $E$ is Young’s modulus of elasticity, $\nu$ is Poisson’s ratio, $U_i$ is the applied displacement and $\sigma_0$ is the equivalent of applied remote stress. For all the FE models the elastic isotropic material with $E=206$ GPa, $\nu=0.3$ is used. The value of $\sigma_0=100$ MPa for all the models is assumed. Of course, the value of applied $U_i$ is varied, depending on the length of the plate ($L$), as it is shown in Figure 1.

As it can be seen from Table 1, the first four models correspond to blunt notches, whereas the last two represent the sharp notch configurations. Furthermore, the models 2 and 4 are the scaled-up notches (only in $xy$-plane) of the corresponding models 1 and 3 respectively. The sample mesh

Figure 1 The geometrical parameters of 3D periodic notched plate and boundary conditions.