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On propagation of time-harmonic elastic waves through a double-periodic array of penny-shaped cracks

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A B S T R A C T

Improved boundary integral equation method for the investigation of time-harmonic longitudinal elastic wave penetration through a plane of penny-shaped cracks with a periodic square or rectangular lattice in 3D infinite elastic solid is proposed. Under the assumption of normal incidence of wave, the corresponding symmetric wave scattering problem is reduced to a boundary integral equation for the displacement jump across the crack-surfaces in a unit-cell by means of a 3D double-periodic Green's function in terms of the exponentially convergent Fourier integrals. A regularization technique for this Green's function involving special lattice sums in closed forms is adopted, which allows its effective calculation in a wide range of wave numbers. A collocation method is used for the solution of boundary integral equation. The reflected and transmitted far-field displacements are shown to be a superposition of a finite number of propagating wave modes and expressed by the obtained solution. The crack-opening-displacements, wave reflection and transmission coefficients in dependence on the wave number, lattice and crack sizes are computed and analysed.

Keywords: Periodic penny-shaped cracks; Elastic wave reflection and transmission; Boundary integral equation method

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1. Introduction

Propagation of elastic waves in solids containing arrays of periodically arranged inhomogeneities of various kinds is an important research subject in the modern fundamental and applied sciences due to the various remarkable phenomena related to phononic crystals, metamaterials properties, as well as ultrasonic quantitative nondestructive material evaluation. In general, they are caused by the constructive or destructive wave interference in such structures with the exhibition of different wave reflection and transmission portions in the frequency spectra, in particular stop-bands or band-gaps at certain frequencies (see Sigalas et al., 2005; Gazalet et al., 2013; Kutsenko et al., 2013; Sukhovich et al., 2013). In this respect, the vectorial character of the elastic wave field and the possibility of the wave mode transformation by the scatterers provide more rich physics of the periodic elastodynamic problems, especially in 3D case, in comparison with the wave propagation problems in photonic crystals. From the point of view of the applications of metamaterials, it is also important to perform the wave propagation analysis in the range of intermediate and high frequencies, when the wave-length is comparable with the size of the scatterers, that was detailed in Lu et al. (2009) and Chen and Huang (2015). Special attention of the investigation concerns the situation with periodic cracks on the path of the elastic wave propagation, because specific wave patterns and wave guide conditions can be generated in this case due to the sharp edges of the scatterers and the planar configuration of the grating as was shown in Danicki (2002), Aliva-Pozos et al. (2010) and Every (2010).

It should be remarked here, that the model of an infinite array of periodically distributed cracks allows us to simplify the frequency-domain analysis of the crack interaction problem by exploiting the special structure of the solutions following from the periodicity conditions formulated by Bloch (1928). In this model, only a reference crack in a unit-cell has to be considered, unlike the crack interaction problems with a finite but large number of interacting cracks, where computational difficulties may appear with increasing number of interacting cracks.

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