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Enhancement of fatigue life of net section in fitted bolt connections

J.T. Maximov [a], G.V. Duncheva [b,*], N. Ganev [c]

[a] Department of Applied Mechanics, Technical University of Gabrovo, 5300 Gabrovo, Bulgaria
[b] Department of Machine Elements, Technical University of Gabrovo, 5300 Gabrovo, Bulgaria
[c] Department of Solid State Engineering, Czech Technical University in Prague, 115 19 Prague 1, Czech Republic

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ABSTRACT

The basic idea of this paper underscores enhancement of fatigue life of the net section in bolted connections by means of the developed method whereby beneficial residual hoop compressive stresses, distributed almost uniformly along the hole axis, are created around the bolt hole. Since the method includes bolt hole cutting up to a precise size after preliminarily cold hole expansion, it is especially appropriate for fitted bolt connections. In the case of conventional cold hole expansion the residual compressive hoop stresses are characterized by significant axial gradient and a tensile field sometimes arises on the hole entrance face. The proposed method homogenizes the compressive field around the bolt hole in an axial direction by means of residual hoop stress redistribution. These stresses significantly reduce the operating tensile stresses at the net section points. Due to the tensile operating load, the resultant hoop normal stresses (superposition from residual compressive and operating tensile stresses) at the net section points are significantly smaller in comparison with the conventional case. The developed method has been studied both experimentally, by X-ray diffraction technique, and numerically, by finite element (FE) simulations. Four FE models have been developed for investigation and optimization of the proposed approach. Application of this approach enhances the fatigue life of the net section in bolted connections due to operating tensile stress reduction.

1. Introduction

Bolted connections are among the widespread connections in metal structures because of their undisputed advantages: large load-carrying capacity due to significant pressing forces between connected plates with possibility for controlling these forces, possibility of repeated assembly and disassembly without causing damage to the components, and assembly of components of significant weight in the cases when welding connections are inappropriate. A critical spot in metal structures are the fields around the bolt holes in structural components which appear to be natural stress concentrators. Within these zones, especially in instances of dynamic load, the potential critical places of fatigue crack beginning and growth are localized. Therefore, the fatigue life, load-carrying capacity and safety of the metal structures with bolted connections depend on the material behavior around the bolt holes.

In the investigations of bolt connections experimental [1,2], numerical (finite element (FE) simulations) [3–5] and combined [6–9] approaches have been used. Regardless of the approach, most studies either aim at creating beneficial data for design of metal structures with bolt holes or are focused on updating of existing standards and other technical regulations in this field.

Part of the investigations [5] of bolted connections is devoted to net section failure (Fig. 1). In view of the loading character, this kind of failure is of great significance to fitted bolt connections; the latter being the object of the present study. The bolts loaded by shear forces are fitted without a clearance in their holes in order to minimize the bending stresses due to the relative skidding between the connected plates.

As a whole, the calculations of the structural components with bolt holes are made without taking into account the residual stresses around the holes. It is well known that the presence of residual hoop normal compressive stresses σ_t^{res} is a precondition for multiple increase in the life time and safety of the metal structures [10]. These stresses (Fig. 1) close the existing micro-cracks and impede the growth of new ones. Conversely, the residual tensile hoop stresses vastly reduce the components life-time, especially when the applied operating stresses are tensile. Because of the external longitudinal load producing remote stresses σ_x (see Fig. 2) and the contact between the fitted bolt shanks and the plates, the residual hoop normal stresses σ_t^{res} around the bolt holes have a paramount importance for the lifetime and safety of the structures.

It is known that because of the temperature factor predominance, the cutting of metals in most cases introduces tensile residual stresses in the superficial layers [11]. Because of necessity for relatively accurate sizes, the fitted bolt holes are processed by cutting. As a result of the conventional manufacturing process containing only cutting

* Corresponding author. Tel.: +359 66 827312.
E-mail address: duncheva@tugab.bg (G.V. Duncheva).

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