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Tensile behaviour of threaded steel fasteners at elevated rates of strain

H. Fransplass [a,b,*], M. Langseth [b], O.S. Hopperstad [b]

[a] Norwegian Public Roads Administration, Directorate of Public Roads office, P.O. Box 8142 Dep, NO-003 Oslo, Norway
[b] Structural Impact Laboratory (SIMLab), Centre for Research-based Innovation and the Department of Structural Engineering, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

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ABSTRACT

The tensile behaviour of threaded steel fasteners was studied experimentally at elevated rates of strain. Two testing techniques were used to perform the tests at strain-rates in the range from 10^{-3} to $1.9\times10^{3}\,s^{-1}$. The tests at low and medium strain-rates were performed in a servo-hydraulic testing machine, while tests at high strain-rates were achieved using a split-Hopkinson tension bar. All tests were carried out using a purpose-made fixture to ensure uniform test conditions, and to control the location at which failure by thread shearing could occur. The material tests and the threaded assembly tests showed approximately the same trend of an increased strength with increasing strain-rate. Owing to the strength ratio between the purpose-made fixture and the threaded fastener, two of three possible failure modes occurred during the performed tests, i.e. bolt breaking and bolt thread stripping. The length of the thread engagement, the grip length and the strain-rate had an influence on the failure mode. In addition, these parameters had varying effect on the strength and ductility of the threaded assembly. A modification of the Alexander [4] model was proposed, to predict the maximum load and mode of failure of threaded steel fasteners at high strain-rates. The modified model was in good agreement with the experimental results.

1. Introduction

External threaded fasteners (bolt, screws and studs) in combination with internal threads (nuts and tapped holes), denoted threaded assemblies, are used in a wide range of engineering structures, such as buildings, bridges, vehicles, passive sign posts and safety barriers. For example, the performance of a deformable safety barrier (consisting of a steel post and steel beams) during a vehicle impact, depends on the behaviour of the threaded assembly. The bolt/nut combination is the connection between the posts and the beam rail, and the behaviour of these connections can have a significant influence on the crashworthiness of such a structure. The bolt/nut combination experiences high deformation rates during a vehicle impact. Even so, the design of threaded fasteners and threaded assemblies is often based on material properties that are obtained at low strain-rates. This may lead to structural components that are not optimal with respect to energy absorption and load distribution. Hence, before a structural impact can be analyzed, the behaviour of each of the involved component must be known. This analysis should be performed with material properties that are obtained at a strain-rate level that is representative for the impact situation.

The stress, deformation and damage distributions in threaded assemblies at quasi-static loading conditions have been a subject of major interest during the last century. Den Hartod [1] examined the stress concentrations in the threads of bolt/nut combinations. This work showed that the load along the length of a bolt/nut combination was not uniformly distributed. Goodier [2] pointed out that some parts of the threads will be free from load, then yielding will occur in the loaded threads and this will modify the load distribution. Sopwith [3] proposed an extended theoretical analysis of the load distribution, and the developed theory has gained general acceptance and shown good agreement with experiments. A method to predict the maximum load and mode of failure of threaded assemblies at quasi-static loading conditions was proposed by Alexander [4], and this method is used in several design codes. Combined quasi-static tension and shear tests on M20 black bolts with property class 4.6 were performed by Shakir-Khalil and Ho [5]. A result from this investigation was that the calculated tensile strength of individual fasteners was different from the tensile strength calculated based on coupon tests. It was pointed out that this was a direct result of relatively low recommended values of the tensile stress area for individual fasteners. The tensile stress area was calculated according to ASME B1.13M [11]. A conclusion from this work was that the material tests are a poor guide to predict the behaviour and the ultimate load-carrying capacity of the bolts. Kulak et al. [6] have reported results on different bolt/nut combinations that were exposed to tension, shear or torsion loads.

A literature survey concerning the behaviour of threaded fasteners subjected to higher strain-rates has been performed, and only the report by Mouritz [7] was found. He examined the

* Corresponding author at: Structural Impact Laboratory (SIMLab), Centre for Research-based Innovation and the Department of Structural Engineering, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway.
E-mail address: henning.fransplass@vegvesen.no (H. Fransplass).

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