Review


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Abstract

The paper gives a bibliographical review of finite element methods applied for the analysis of fastening and joining from the theoretical as well as practical points of view. The bibliography at the end of the paper contains 726 references to papers and conference proceedings on the subject that were published between 1990 and 2002. These are classified in the following categories: pin joints; thread connections; bolted joints, screws, nuts; rivets; fittings; tubular joints; expansion joints; gaskets; and other types of fastening.

Keywords: Finite element; Bibliography; Fasteners; Joints

1. Introduction

The output of scientific papers in general is fast growing and professionals are no longer able to be fully up-to-date with all the relevant information. The increasing specialization in various engineering fields has resulted in the proliferation of subject-oriented journals and conference proceedings directed to specialist audiences. The researchers have more channels for communicating the results of their research at their disposal, but on the other hand finding the necessary information may be a time-consuming and uneasy process. Another question is whether researchers/scientists are willing to spend time looking for information. It has been pointed out that in engineering, informal knowledge channels are the most frequently used means of obtaining information.

In the last almost four decades the finite element method (FEM) has become the prevalent technique used for analyzing physical phenomena in the field of structural, solid, and fluid mechanics as well as for the solution of field problems.

Fastening and joining are defined as an act of bringing together, connecting or uniting to becoming one or a unit. There are many types of fasteners such as bolts and nuts, adhesive bonds, welds, etc. This paper concentrates mainly on mechanical fasteners. Mechanical fasteners are used in assemblies for their strength, reusability and appearance. Readers interested in welding are referred to Refs. [1,2] and in bonding to Refs. [3,4].

The bibliography is divided into the following parts and concerns:

- Pin joints;
- Thread connections;
- Bolted joints, screws, nuts;
- Rivets;
- Fittings;
- Tubular joints;
- Expansion joints;
- Gaskets;
- Other types of fastening

The bibliography is organized into two main parts. In the first, each topic is handled and current trends in modelling techniques are mentioned, usually as the keywords. The second part, Appendix A, contains a list of papers published in the open literature in the period of 1990–2002 on subjects listed above. References have been retrieved from the author’s database, MAKEBASE. Also the INSPEC and COMPENDEX databases have been checked. Hopefully, this bibliography will save time for readers looking for information on finite element analyses of mechanical fastening and joining. Readers interested in the finite
element literature in general are referred to the author’s Internet Finite Element Books Bibliography (http://www.solid.ikp.liu.se/fe/index.html) where approximately 500 book titles are listed and completed with bibliographical data and abstracts. Other author’s bibliographies in connection with the analysis of pressure vessels and piping, where FEMs are applied, can be found in Refs. [5–7].

2. Finite element analysis of fastening and joining

2.1. Pin joints

Pin joints represent either 3D double shear or 2D single shear joints that are applied in many engineering structures from the skeletal frameworks to the outer skin of aircraft, automobiles, buildings, pressure vessels, etc. The stresses and slips in the vicinity of contact regions determine the static strength, plasticity, frictional damping and vibration levels, and affect the structural performance as, for example, the fatigue life, earthquake resistance [8]. The FEM makes it possible to analyse/simulate the more realistic pin connections, not only a single pinned joint as is possible by using analytical, closed-form methods. The effect of various parameters (dimension, geometry, material, friction) on the contact area, contact pressure and tangential stress distribution can also be studied.

The use of composite materials to strengthen engineering structures has received considerable attention in recent years. Mechanical joining is easier and more economical than, for example, adhesive bonding but it is necessary to drill holes resulting in large stress concentrations. Some papers listed in Appendix A deal with stress and failure predictions in mechanically fastened joints in composite laminates. Applied finite element models can take into account the contact interface, large deformations, nonlinear shear stress–strain, progressive damage and other factors. A review of analytical and numerical methods applied in mechanically fastened joints in fiber reinforced plastics is in Ref. [9].

Topics included. 2D and 3D static and dynamic analysis of single- and multi-pin joints; deformation, stress and failure analysis; thermomechanical analysis; buckling analysis; strength analysis; determination of load distribution; effects of material nonlinearity; effect of temperature; effect of interface fits; thickness effects; contact problems; fretting and wear; fracture mechanics problems; progressive failure analysis; fatigue crack growth.

2.2. Thread connections

Threaded components are the most important structural elements influencing significantly the strength and endurance of the whole structural assembly. Threaded connections are used for their ability to develop a clamping force and for the disassembly possibility that is important for maintenance. When a dynamic load is applied as is the case in many assemblies, failure may occur due to fatigue and vibration induced loosening. These failures can be avoided by proper joint design where the finite element studies can be helpful. A review of the load and stress distributions in the threads of fasteners can be found in Ref. [10].

Topics and types of threaded connections. 2D and 3D analysis of threaded connections; dynamic behavior of threaded connections; thermomechanical analysis; stress concentration at threaded roots; complex stress distribution in threads; load distribution between threads; axial and bending stress concentration factors; fracture mechanics problems; strength analysis; fatigue analysis and life estimation; stress intensity factor for threaded joints; residual stresses in threaded connections; effect of cracks on load distribution; effect of taper variation; helical effect on threads; threaded fasteners; geometrically exact threads; conical threaded connections; buttress threads; drillstring threaded joints; threaded end closures; threaded pressure vessels; threaded pipes.

2.3. Bolted joints, screws, nuts

The FEM can study bolted joints with finite sliding deformable contact where the helical and frictional effects on the load distribution of each thread are included. The studies of bolted connections are rather complicated because the model should be 3D (2D solutions give stiffer and stronger results) and take into account many factors such as material and geometrical nonlinearities, contact, friction, slippage, bolt-plate interaction and fracture. The quality of computed results also depends on the element type used, discretization, constitutive equations, step size, kinematic description, etc. Finite element modelling has been extended to study the structural behavior of cold-formed steel bolted connections. The advantages of using cold-formed steel are derived from their long-term durability and high yield strength.

Composite materials with bolted joints have also been extensively used in various assemblies in recent years (electronic packaging, aircraft industry, automotive industry, etc.). The local contact between the bolt and composite material may induce high stress concentration and break the material. The stress distribution near the region around the bolt joint where the interaction between the bolt and the loaded hole is taken into account, can be determined by finite element analyses.

Topics and types of connections. 2D and 3D static and dynamic stress and deformation analysis of bolted joints; thermomechanical analysis; heat transfer across bolted joints; effect of thermal loading; thermal contact resistance; assembly stress and deflection; deformation in screw thread; mechanical properties of bolted connections; time-dependent behavior of bolted joints; effect of bolt threads on the joint stiffness; computation of member stiffness; tensile behavior of bolted joints; bolted joints subjected to high
eccentric loads; load distribution studies; load distribution in bolt-nut connector; centrically loaded bolt joints; load distribution in screws; determination of bolt forces; environmental effects; fracture mechanics problems; ultimate limit load calculation; strength analysis; stress intensity factor; mixed-mode fracture; contact problems; thermoelastic contact problems; constraining effect of bolted joints; fatigue analysis; damage; progressive damage modelling; lifetime prediction; deformation and fracture of nuts; separation problems of bolted connection; bending of a screw plate; prying and shear in end-plate connection; axial loads due to screw fastening; relaxation in bolted connection; tightening process of bolted joints; bolted joints with various clamping configurations; bolted joints with tensioner; prestressed bolted connections; prestressed screw joints; pretension in bolted connections; leakage of bolted flanged joints; nut-bolt connections; axisymmetric bolt joints; end-plate connections; isolated and extended bolted end-plate connections; semi-rigid bolted end-plate connections; semi-rigid bolted beam connections; bolted flanged connections; rectangular bolted flanged connections; flanged connections for high temperature applications; bolted joints at cryogenic temperature; bolted beam to column joints; cold formed bolts; cheese-head bolts; countersunk bolts; U-bolts; self-threading bolts; rockbolts; bolted brackets; swaged bolts; railroad bolts; anchor bolts; cable bolt support system; bolt-nut-washer-compressed sheet joints; hollow type bolted joints; stud bolt fastening; multiple-row bolted connection; multiple-bolted joints; bonded/bolted joints; single lap screw connection; ball-screw joints; bolted connections in wood; bolted connections in composites; combining adhesive with bolts.

2.4. Rivets

Topics of this section. 2D and 3D static and dynamic riveted joint modelling and analysis; fracture mechanics problems; joint failure; strength evaluation; fatigue life prediction; stress intensity factor; crack nucleation; fretting problems; energy absorption; skin-rivet contact prediction; effect of interference and clamping on fretting; residual stresses; riveted joint design; laminates connected by rivets; riveted single lap joints; adhesively bonded joints with rivets; riveted airframes.

2.5. Fittings

Topics and type of fittings. 2D and 3D mechanical and thermomechanical analysis of fit joining; stress and deflection analysis; thermally loaded fits; fracture mechanics problems; contact problems; creep at the interface; stress intensity factor; fatigue evaluation; residual stresses; press fits; clearance-fit joining; interference fits; shrink-fits; end fittings; crimped end fittings; ball snap-fits; cantilever snap-fits; L- and U-shaped snap-fits; bayonet-finger snap-fits; elbow and tee fittings; pipe fittings; plumbing fittings; fitted cylindrical liners.

2.6. Tubular joints

Some structures, i.e. offshore structures, consist of a large number of tubular members connected to one another by special joints. Tubular members are jointed together at their intersections in a variety of geometrical forms. These joints represent structural discontinuities that give rise to stress concentrations. Parametric finite element studies can generate a database of stress concentrations and degree of bending for various geometries of tubular joints.

The combination of high stress concentration with dynamic loads makes fatigue damage almost unavoidable. Due to high stress concentrations, plastic deformation can occur at the intersection before the ultimate failure of the joint. The elastoplastic finite element analyses can estimate the static and fatigue strengths of tubular joints. In computations various conditions such as combined modes of loading, size effects, materials, environmental factors, etc. can be included to get a more realistic stress behavior of an entire tubular joint. A review of fracture mechanics models for tubular joints is in Ref. [11] and various methods for determining stress intensity factors for these joints are discussed in Refs. [12,13].

Topics and types of tubular joints. 2D and 3D linear and nonlinear stress and deflection analysis; static and dynamic studies; stress concentration factors; force-displacement characteristics; joint flexibility; hot spot stresses; influence of loading on the joint performance; fracture mechanics problems; strength and failure analysis; ultimate strength analysis; stress intensity factors; cracked tubular joints; damage; fatigue; multiaxial fatigue; residual stresses; NDT detection of cracks; effect of imperfection on the strength; stiffened and unstiffened tubular joints; multiplanar tubular joints; square-to-round tubular joints; square-to-square tubular joints; tubular joints with brackets; tubular lap joints; overlapped tubular joints; plate-reinforced tubular joints; circular flange joints; grouted tubular joints; composite-to-metal tubular joints; tubular stub-columns; K-, L-, T-, X-, Y-, ST-, KK-, DT-, DX, XX-, XT and YT-tubular joints.

2.7. Expansion joints

Topics and types of expansion joints. 2D and 3D static and dynamic analysis of expansion joints; creep, shrinkage and temperature effects; fracture mechanics problems; residual stresses; fatigue analysis; expanded tube-to-tube sheet joints; modular expansion joints; bellows-type expansion joints; expansion joints for seismic protection; expansion joints in piping systems.
2.8. Gaskets

Topics and type of gaskets. Stress analysis and sealing performance of gaskets in bolted flanged connections; contact problems; creep relaxation; determination of stress levels during thermal transients; local bifurcation problems; support testing; sheet gaskets; spiral wound gaskets; layered gaskets; cylinder block gaskets; taper-seal gaskets; plug, claw and gasketed closures.

2.9. Other types of fastening

Topics of this section. 2D and 3D, linear and nonlinear analysis in and around fasteners in general; load distribution; creep relaxation; residual stresses; contact problems; fracture mechanics problems; failure strength prediction; progressive damage modeling; cracking near fastener holes; effects of fastener hole defects; cold-worked fastener holes; fatigue life prediction; stress intensity factor; structural fasteners for bracing connectors; multiple fasteners; mechanically fastened joints in composites; fastening elements in concrete; mechanically fastened lap joints; track fastening; fastening in automotive engineering; smart structural fasteners.

Acknowledgements

The bibliography presented in Appendix A is by no means complete but it gives a comprehensive representation of different finite element techniques applied to the analysis of fastening and joining. The author wishes to apologize for the unintentional exclusions of missing references and would appreciate receiving comments and pointers to other relevant literature for a future update.

Appendix A. A bibliography (1990–2002)

This bibliography provides a list of literature references on finite element analyses of fastening and joining, theory and applications. The listing presented contains papers published in scientific journals, conference proceedings, and theses/dissertations retrospectively to 1990. References have been retrieved from the author’s database, MAKE-BASE. Entries are grouped into the same sections described in the first part of this paper, and sorted alphabetically according to the first author’s name. In some cases, if a specific paper is relevant to several subject categories, the same reference can be listed under the respective section headings, but the interested reader is expected to consider also areas adjacent to his/her central area of research interest.

References


Further Reading

Pin joints


Thread connections


**Bolted joints, screws, nuts**


**Rivets**


**Fittings**


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Gaskets


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Other types of fastening


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