Design of Mechanical Joints

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Preface

The use of mechanical fasteners and joints in the making of common products can be traced to the early history of civilization. The corresponding first signs of primitive joint technology should perhaps be judged on a par with the importance of the invention of the wheel. Since the primary function of a conventional joint is to transmit a given load from one piece of a material to the adjoining one, the collective mission of the various fastening schemes has always been, so to speak, to hold the world of mechanical systems together.

The purpose of this book is to highlight the practical aspects of design methodology applicable to typical joints held in place by rivets, bolts, weld seams, or adhesive materials. The book attempts to bring together a number of topics treated in discrete volumes of the Mechanical Engineering Series, edited for Marcel Dekker, Inc., by L. L. Faulkner and S. B. Menkes. The specific references from this series have been particularly helpful in the development of design information for the bolted and adhesive connections.

Competitive industrial practice demands that the knowledge of design and performance of mechanical and structural joints be readily available. Yet the behavior of individual fasteners and the relevant interfaces is often little understood despite the progress in numerical and experimental techniques. This state of knowledge, however, is not surprising when we realize that the problem of design and performance of a single bolted joint can involve as many as 76 variables. The challenge is compounded further by our training, which has traditionally centered around the theoretical models of individual components rather than interfaces and systems. Since no single volume can do justice to the entire area of joint methodology and the mechanics of interfaces, this book is limited to practical results and formulas intended for the preliminary design.

In keeping with the design-oriented philosophy, Chapters 1 and 2 provide an introduction to joint mechanics, strength of materials, and fracture control applicable to the analysis of mechanical connections. The basic characteristics of individual fasteners, riveted joints, and bolted connections are given in Chapters 3 and 4. This material forms a background for the subsequent discussion of analysis and design of either plain or reinforced flanged configurations described in some detail in Chapter 5. The information on flanges selected for this book is specifically directed toward the role of gaskets, as well as heavy-duty flanged connections based on the metal-to-metal contact. Chapters 6 and 7 are concerned with a number of common joint configurations such as clamps, couplings, pins, pipe supports, and other elements which may or may not require the use of the conventional fasteners.

Chapter 8 constitutes a practical design guide to welded joints, their types, and advantages and limitations of interest to mechanical and structural designers. Special interfaces created by the use of diaphragms, diagnostic windows, structural barriers, and positive expulsion devices represent areas closely related to joint technology. Hence, the corresponding design equations, configurational details, and test results are compiled in Chapter 9. Finally, state-of-the-art information on mechanical design of adhesive joints as well as the technology of several adhesive materials are treated in

Chapter 10. This chapter describes the characteristics of setting and flow and shrinkage of adhesives and provides the basic formulas for design of butt, lap, and scarf adhesive joints. Specifically, the design equations are given for the calculation of stresses and the allowable loads. The chapter ends with a critical overview of adhesive material selection and modern developments in the field.

This book is intended for a wide range of engineering practitioners and offers a central source of design information with up-to-date references spanning the field of fastener and joint technology. The essential design formulas are presented in simple mathematical language with the emphasis on the hands-on approach to the study of individual fasteners and joints. Each chapter dealing with practical engineering matters includes a summary of the particular design considerations, definitions of symbols employed, and a list of references on which the chapter material is based. Since the topics discussed throughout this volume involve a very limited number of dimensional quantities, the formulas and the material properties are expressed in the customary system of English units.

Over the past few years, a number of individuals and organizations influenced the scope and the contents of this book by means of published work, written contributions, and personal communication. The extensive knowledge and experience reflected in publications of J. H. Bickford inspired the treatment of single fasteners, complete bolted joints, and material parameters which formed the basis of Chapters 3 and 4. Numerous technical exchanges and long-standing contact with J. Webjørn of Sweden contributed to a critical review of modern joint preload criteria and compact flange theory included in Chapters 4 and 5. Several staff members of the Lawrence Livermore National Laboratory played a part in the logistics and technical effort in developing the manuscript material. R. J. Wasley rendered professional endorsement, encouragement, and special guidance related to the various intricacies of publishing experience. J. R. Page, K. A. Peterman, and R. G. Koger contributed hard-to-come-by experimental data for the analysis and design of vacuum barriers featured in Chapter 9 on mechanical interfaces. A. M. Davito provided major assistance and technical scrutiny during the development of Chapter 8, dealing with the practical aspects of welding technology and engineering theory of weld design. Such contributions are gratefully acknowledged.

The transformation of the handwritten notes into a legible text required painstaking composition and keyboarding. Shirley A. Calvert coordinated the preliminary typing and prepared the first draft of the manuscript. Janice Y. Brosius attended to numerous processing details of the format, mathematical symbols, and tabular matter in developing the camera-ready features of the material. Carol A. Addison provided assistance during the various stages of this work and executed the final corrections. The author extends his deep appreciation and acknowledges all the efforts and skills of the operators involved in the process.

Last, but not least, the author is indebted to R. B. Carr for his interest and help during the crucial phases of bringing this book project to a successful conclusion.

Although no effort has been spared to assure the correctness of the technical matter and due mention of the various references and contributions, it is, perhaps, too much to hope that all errors and omissions have been avoided. The author therefore welcomes the calling to his attention of any of the shortcomings that may be uncovered.

Alexander Blake

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1

Introduction to Mechanical Joints

Traditionally our design knowledge has been centered around the treatment of individual structural components and elements of machines. Many models and design formulas have been developed from classical theories taking discrete elements of a particular load carrying member into consideration. Such formulas have been gradually refined to yield more dependable results from the point of view of safety and economy.

Design of mechanical joints rather than individual components presents a special challenge. The behavior of a joint is often so complex that a single design formula cannot be used to make a reliable prediction. Emphasis on a single component, although quite important, may result in neglect of those mechanical interfaces and interactions which can be influential on the total response of the complete mechanical system. Hence, a poorly

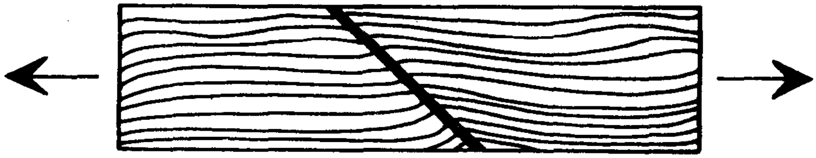

Fig. 1.1 Scarf joint.

designed joint represents a weak link in the overall behavior of the structure or a machine in service.

The basic function of a mechanical joint is to transmit a given load from one piece of material to the adjoining one. Since the external load causes the development of a stress field, hence, the mission of a joint is also to transfer the stress across a mechanical boundary, hopefully without undue gradient. This is pretty much the case with an example of glued scarf joint shown in Fig. 1.1, which can be used, say, in a wooden structure.

In a metal structure involving a welded design a butt-joint configuration is often used such as that shown in Fig. 1.2.

Among the obvious disadvantages of this type of a welded joint is the possibility of a tensile failure in the case of crack propagation across a heat affected zone. Nevertheless, the stress concentration per se is avoided because of a relatively smooth

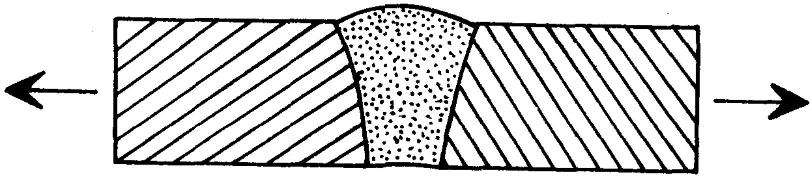

Fig. 1.2 Butt joint.

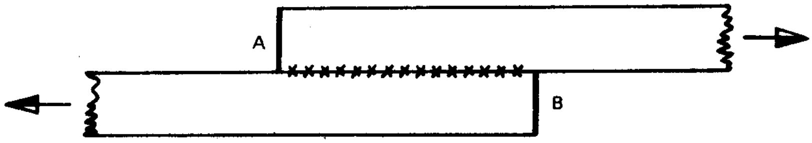

Fig. 1.3 Stress concentration in a lap joint.

transition from one side of the joint to the next. Hence, there is certain similarity in the case of scarf and butt-joint configurations with respect to the load transfer. Various types of welds are described in some detail in Chapter 8. The basic design parameters of adhesive scarf joints are given in Chapter 10.

When a mechanical joint involves a lap configuration such as that shown in Fig. 1.3, certain degree of stress concentration cannot be avoided. The actual bonded length is AB with the maximum stresses likely to develop at A and B.

As long as this lap joint is relatively rigid, it makes little difference whether the joint is riveted, bolted, welded, screwed, nailed or glued. In the case of a special mechanical joint illustration in Fig. 1.4, a nylon thread is cast into a block of plastic material. Essentially Fig. 1.4 attempts to describe the two extreme modes of behavior involving different relative rigidity of the components [1.1].

The foregoing simple illustration contains a very important lesson of joint mechanics. For instance, when a low-modulus thread is being pulled out of a rigid block, having a high modulus, the resistance of the thread to pull-out is practically independent of its length. Hence, as far as a thrush is concerned a short worm is

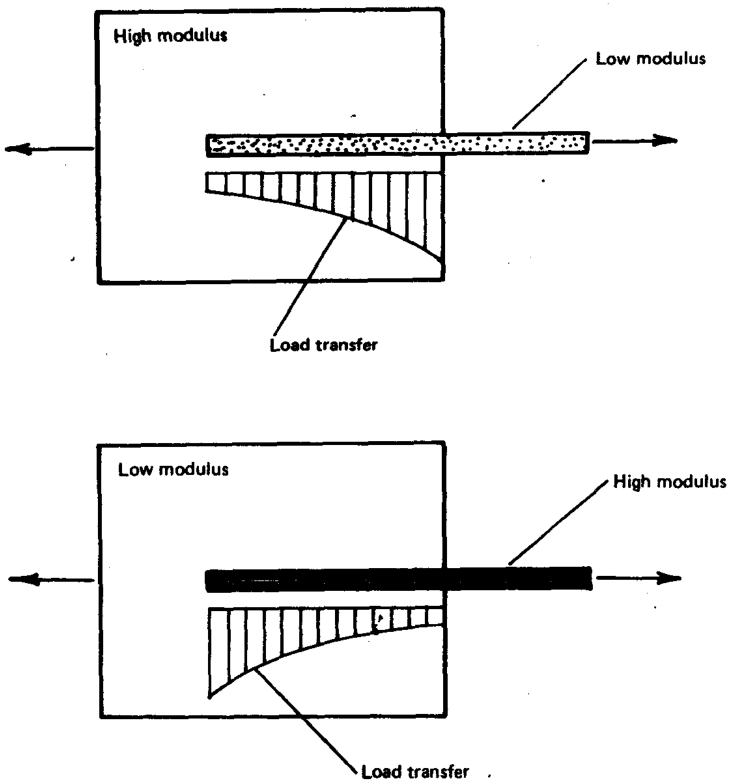

Fig. 1.4 Dependence of load transfer on modulus.

just as hard to extract from a lawn as a long one. This interesting principle has important practical applications in experimentation where it may be necessary, for instance, to make a long and complicated hole in a relatively large block of material.

Suppose we now wish to mold several strong wires in a frayed-out configuration into the body of the plastic part as shown in Fig. 1.5. It would certainly appear that if one contemplated the design of some kind of an attachment between the steel wires and

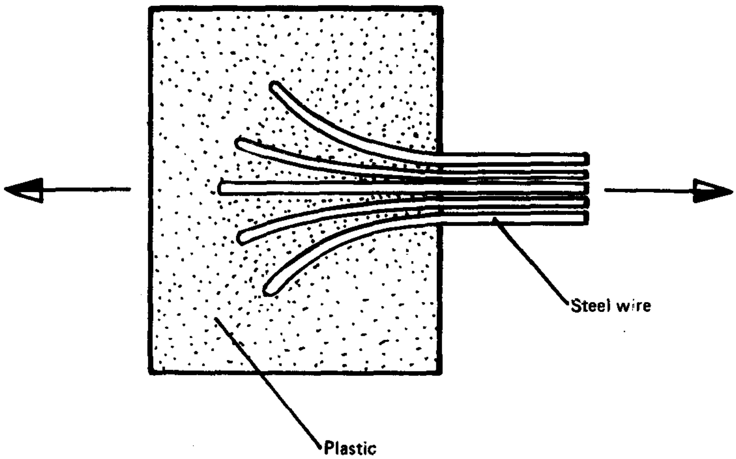

Fig. 1.5 Frayed-out wire joint.

the plastic matrix, the scheme given in Fig. 1.5 might be successful because the frayed-out configuration resembled a tapered mechanical joint keyed inside the plastic. Each individual wire, having relatively high modulus compared to that of the plastic matrix would, of course, involve a stress gradient such as that illustrated in Fig. 1.4. The problem here, however, is that all the individual stress gradients are not necessarily identical in terms of load transfer characteristics and the absolute magnitude of stress concentration. Hence, as soon as one wire approaches the ultimate adhesive strength and begins to pull out of the plastic, the remaining wires must carry additional load so that in practice all wires fail their grip in a succession. The surprising result is that the mechanical joint shown in Fig. 1.5 can at times carry only a small portion of the anticipated design load.

The joints involving the adhesion forces between the metals and the plastics must be designed with great care. The problem we face here is that as soon as the metal reaches its yield strength the mechanism of adhesion is likely to fail. Other ramifications of the adhesive bonding are discussed in Chapter 10.

In further considering the mechanics of load transfer in general, we can select a threaded connection where we note that there are certain similarities between the thread and adhesion type of connections. For instance, the first few threads in a mechanical joint shown in Fig. 1.6 can carry a significant portion of the total load. This specific characteristic of a threaded fastener is reviewed in some detail in Chapter 3. It will suffice to mention here that the curve of load transfer for the threaded portion shown in Fig. 1.6 is quite similar to that illustrated in

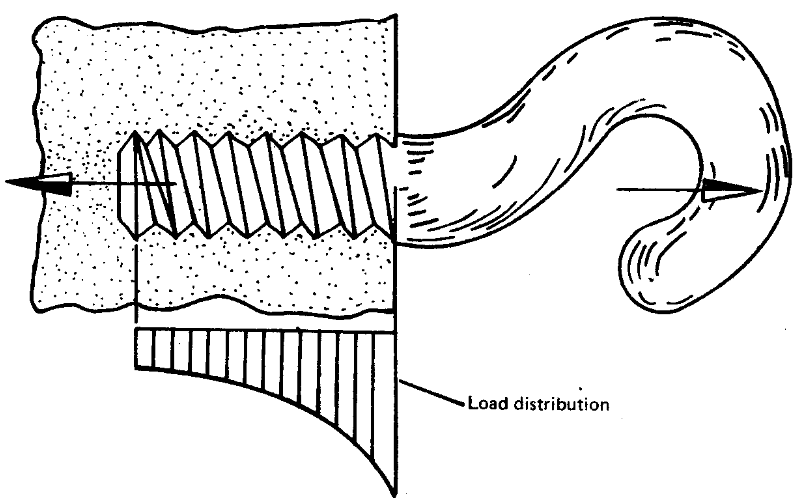

Fig. 1.6 Example of a threaded connection.