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Fretting fatigue

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item, which supersedes ESDU 67012, was monitored and guided by the Stress Analysis and Strength of Components Committee which has the following membership:

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This Item was also accepted for inclusion in the Fatigue Series by the Fatigue Committee, which first met in 1955 and now has the following membership:

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(Continued on inside back cover)

FRETTING FATIGUE

CONTENTS

	Page
1. INTRODUCTION	1
2. DESCRIPTION OF FRETTING FATIGUE	1
2.1 Fretting	1
2.2 Fretting Fatigue	2
3. FACTORS AFFECTING ENDURANCE UNDER FRETTING FATIGUE	4
3.1 Influence of Type of Loading Cycles	4
3.2 Surface Condition	4
3.3 Surface Roughness	5
4. PRACTICAL DESIGN AGAINST FRETTING FATIGUE	6
4.1 Avoidance of Fretting Fatigue	6
4.2 Methods of Improving Endurance under Fretting Conditions	7
4.2.1 Use of anti-fretting compounds or interfay materials	7
4.2.2 Attention to the condition of the surface	7
4.2.3 Design with regard to contact pressure, relative movement and maximum stress	7
4.2.4 Analysis using fracture mechanics techniques	8
5. PHYSICAL APPEARANCE OF DAMAGE DUE TO FRETTING FATIGUE	8
6. DERIVATION	10
7. TABLES	11

FRETTING FATIGUE

1. INTRODUCTION

Under service loading the members of structural joints and mechanical connections experience differential strains. Thus, each loading causes small relative movements at the contacting surfaces. Such action can initiate fatigue cracks and is termed fretting fatigue. The mechanism of fretting fatigue can initiate a fatigue crack very early in the life of a joint or connection and can therefore seriously reduce its fatigue endurance. The action of fretting may reduce the fatigue strength (to failure) at high endurances to 10 per cent or even less, dependent on loading conditions, of the normal, unfretted, fatigue strength. This Data Item is concerned with describing the phenomenon of fretting fatigue in metals and providing guidance on methods of avoiding it. Notes are also provided on the physical appearance of a fretting fatigue failure. Several Data Items provide data on fatigue tests in which the fatigue strength is influenced by the occurrence of fretting. The information provided in this Item will assist with the interpretation and application of the data provided in those Items.

2. DESCRIPTION OF FRETTING FATIGUE

2.1 Fretting

Wear is the general term used to describe the damage that results when the surfaces of two components are rubbed one against the other such that small particles are worn away from one or both surfaces. Fretting is the term used to describe the particular case of wear that occurs when two components are held firmly together. In this, the relative to and fro movement between their contacting surfaces only occurs as a consequence of repeated loading of the members causing differential strains between the members. The relative movements at the contacting surfaces are therefore very small and have amplitudes of less than about 75 μm (0.003 in). If relative movement occurs simultaneously over the whole area of the contacting surfaces then it is not usually characteristic of fretting and is more representative of reciprocating wear.

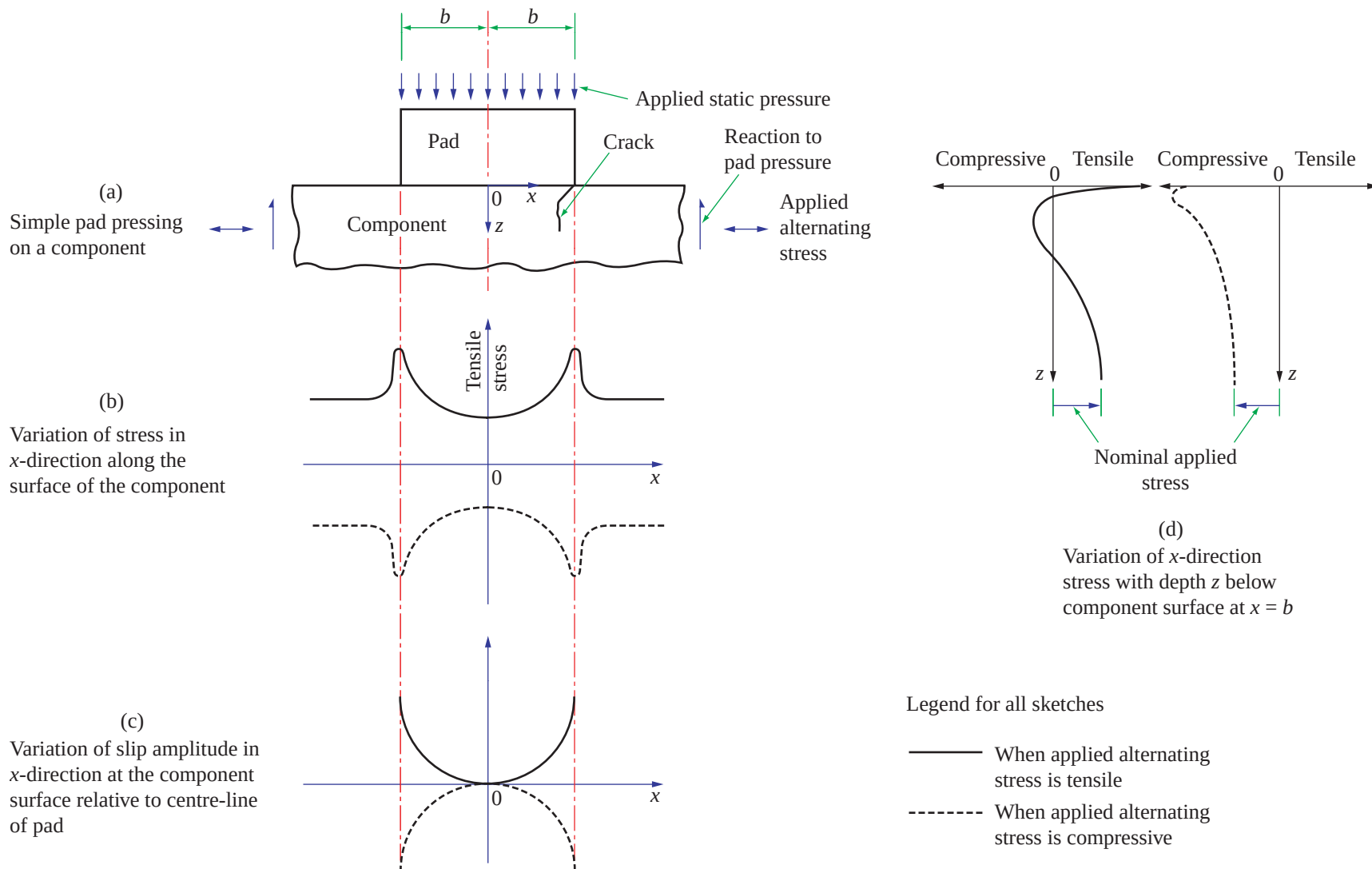
Under fretting conditions surface damage occurs. Several mechanisms may be responsible for the damage. Initially, high spots on the contacting surfaces can form micro-welds between surfaces. In subsequent loadings and movements the micro-welds can be broken and re-made giving a transfer of material, usually to the harder surface. This roughens the surfaces but further fretting smears the material and reduces roughness. Continued fretting action leads to the removal of surface layers by a delamination process in which small plate like particles are produced. These may be the result of metallurgical changes occurring in very small volumes of material on the surface leading to delamination between them and the metallurgically unaffected material below. All these processes produce small particles of metal. The resulting debris of particles is abrasive and, with each loading, contributes to the removal of further material from the surfaces. Additionally, the newly exposed surfaces of the particles can be prone to attack from the environment and can, for example, oxidise. Environmental action may increase or decrease the abrasive properties of the debris. Since fretting is associated with very small relative movements the debris of particles is usually trapped between the contacting surfaces. Thus, only those particles at, or very close to, the perimeter of the area of contact escape. With continued fretting more and more particles are formed and the resulting fine powder can act as a pseudo lubricating layer, so reducing the friction force transmitted between the contacting surfaces.

2.2 Fretting Fatigue

The term fretting fatigue is used for the condition where fretting, as described in Section 2.1 above, causes the initiation of a crack which may subsequently grow by fatigue to cause component failure. In a component subject to fretting, the stresses in the surface layer acting parallel to the surface will be the result of the alternating applied load and the alternating frictional forces transmitted between the surfaces. Fretting fatigue data are commonly obtained from tests where a simple pad is pressed against a surface on a component subject to alternating stress parallel to the surface, as illustrated in Sketch 2.1. In this example the maximum stress occurs at, or near to, the ends of the region of contact. If the maximum tensile stress is sufficiently high it can act with any abrasive particles present to tear the surface and initiate a small crack. Several such cracks are usually produced and some of these can link to form larger cracks. The largest crack will dominate and will grow in width and in depth. The combined action of the applied alternating loading, the forces generated by friction and the direct pressure is to produce a stress field such that initial growth of the crack down into the material is not normal to the surface, as illustrated in Sketch 2.1. Since all such cracks are initiated by the forces generated by relative movement they will all be orientated across the surface normal to the local direction of movement. In practical joints and connections the point where the stresses have a maximum value, and the location at which the crack will form, will depend upon the shape and stiffnesses of the contacting members.

The crack produced by fretting may or may not be sufficiently large to continue to grow under the applied alternating stress. As Sketch 2.1 shows, the local tensile stress at the surface near to the edge of the pad becomes compressive just below the surface thus tending to close the crack. Therefore, under constant amplitude conditions the cracks may not be able to grow out of the region of severe fretting action and fatigue failure will not occur. Typically, such cracks will be less than a millimetre long. However, if, as is the more usual situation, the applied stresses are sufficiently large, the compressive stress will be overcome sufficiently to cause growth and the largest crack will continue to grow. As the crack tip grows away from the area of fretting it becomes less influenced by the fretting action and the surface contact pressure and eventually proceeds as a macro-crack under the action of the applied stress field alone. Because of the early initiation caused by fretting, the endurance is composed almost entirely of growth from a crack produced by fretting into a macro-crack.

The highly damaging effect of fretting fatigue can be illustrated by comparing the fatigue endurance in otherwise identical fretted and non-fretted regions. Without fretting, most of the fatigue endurance is taken up in initiating a fatigue crack and growing it from a micro-crack to become a macro-crack. Typically some 75 per cent or more of the endurance is occupied by this phase of the total growth of a crack. However, when fretting is present, initiation occurs prematurely and the early growth is accelerated by the combined action of the applied alternating stress field and the alternating stress field created by the frictional forces. Thus, under fretting, initiation and growth to a macro-crack are considerably accelerated and only the small fraction of life, attributable to the growth of a macro-crack, is largely unaffected.



Sketch 2.1 Fretting fatigue crack generated by a simple pad pressing on a component that is subject to an applied fatigue loading. Also shown are stress and slip amplitude variations along the surface of the component.