Design of Joints in Engineering.

Introduction

Objective of the lesson

Why the design of joints is so important

Why joints often fail

Objective of the lesson

<u>The prime objectives of this lesson are to:</u>

- Explain the basic principles of joint design
- Provide a description of the options available
- Provide a checklist of factors to be considered in carrying out a design
- Provide guidance on useful sources of design information
- To explain or emphasise important technical terms

€

Why the design of joints is so important

•Most products are made from more than one piece of material; most products, therefore, need joints to hold the pieces together

•The cost of assembling and making joints is frequently the major part of the total production cost

•More products fail from inadequate joints than any other cause

•Many products contain hundreds or thousands of joints. The cost of disassembly and repair of one failed joint can often exceed the cost of an entire new replacement product.

•Inadequate joint design costs the world economy hundreds of billions each year

Why joints often fail

Joint design is still more of an art than a science
Most joints are designed on the basis of experience of previous service performance
Design improvements are often made by trial and error - this is an art
Trial and error is becoming less acceptable as customers' reliability expectations increase

Prototype testing can increase reliability where practicable and when time and resources allow

More reliance is having to be placed on correct prediction of performance - this requires scientific understanding and quantification of joint behaviour
The variety of materials, product forms, joining processes and service conditions in today's hi-tech world is vast. The choice of possible design situations is astronomical.
Scientific testing and design rules only cover a small fraction of the possible design situations

If a designer is to consider solutions outside his/her immediate range of experience, it is necessary to be aware of the general principles of joint design and manufacturing quality problems

Main causes of design failures are therefore:

Lack of awareness of one or more important factors which need to be considered in the design process

Lack of appropriate design data

Lack of resources to conduct the necessary testing

Lack of consultation with production personnel

Joining processes

The most widely used methods of joining are:

Fusion welding

Forging processes

Brazing and soldering

Adhesive bonding

Mechanical fastening

Reliability

The main factors which affect reliability are:

Accurate prediction of service conditions

Accurate prediction of performance

Control of materials quality

Control of joining process

Inspection/testing of completed joints

Control of service conditions

Fundamental geometry types

For wrought products

Products made by rolling, extrusion, drawing, etc (and forging to some extent) are usually prismatic in form and long in relation to their thickness and width.

Two fundamental joint geometries arise:

butted joints - where the end of a component butts onto the end or side of another

lapped joints - where the side of one component laps onto the side of another

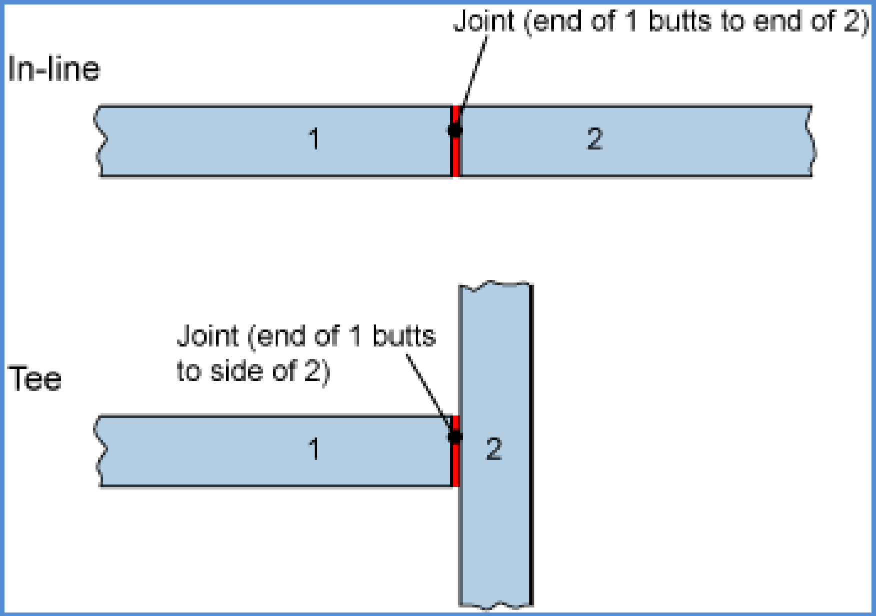
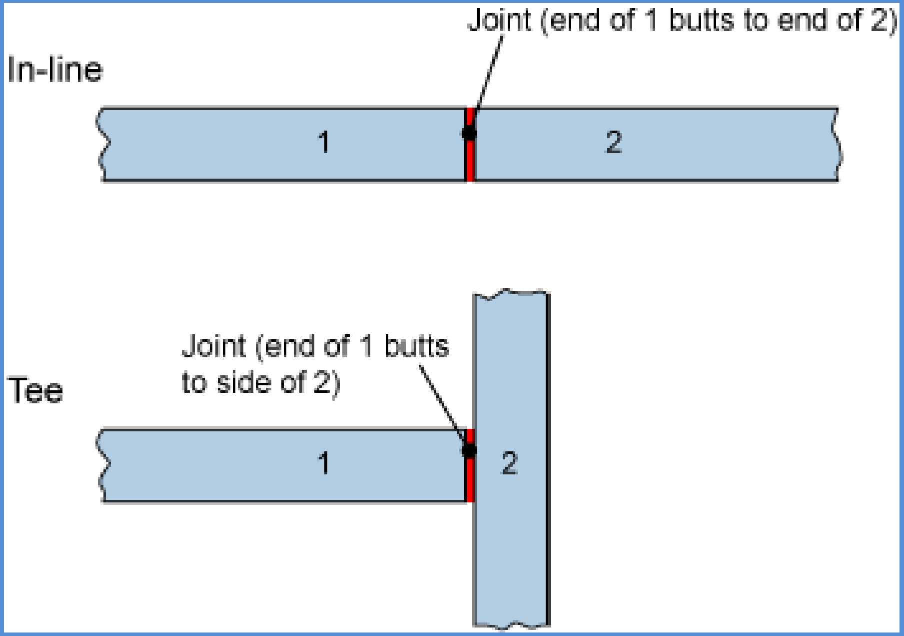


Fig.1. Basic butt joint types



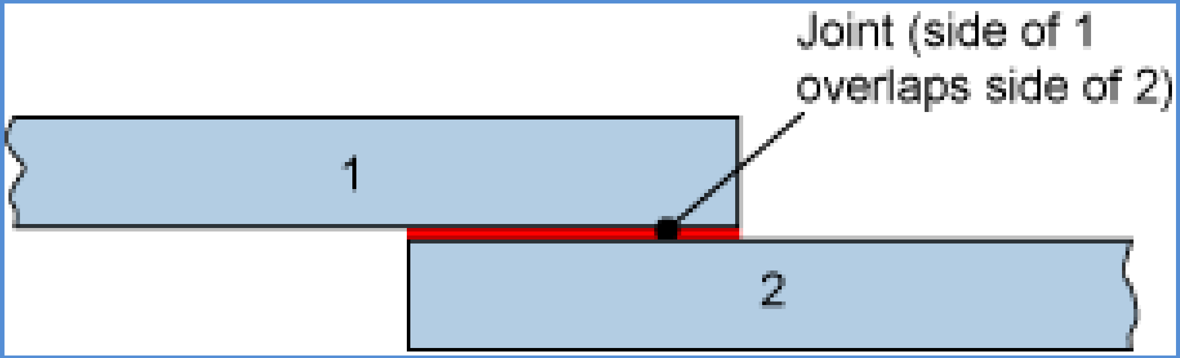


Fig.2. Basic lap joint

Fig.3. Variation of in-line butt joint

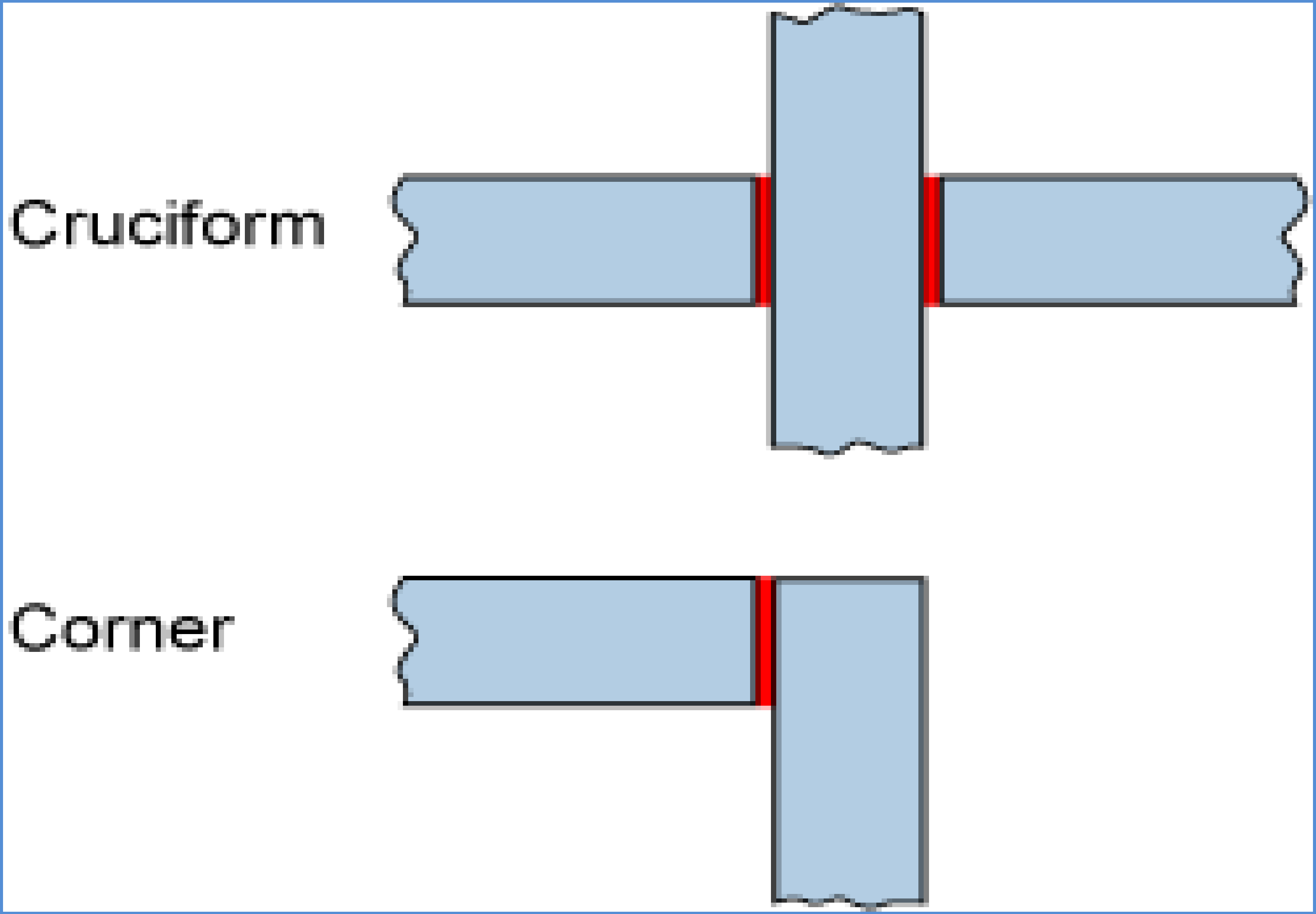


Fig.4. Variations of Tee joint

Advantages of butted joints

More efficient use of material

Lower stress raiser.

Better appearance

Less flow restriction

Easier to keep clean

Generally less prone to corrosion

Less jointing consumable required

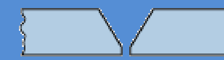
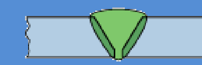
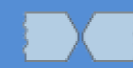
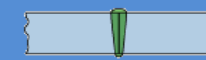
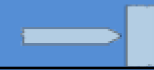
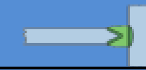
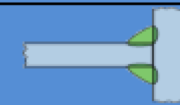
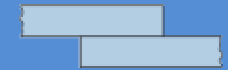
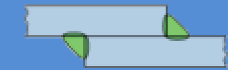
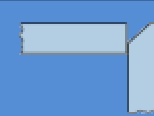
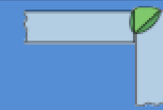
Advantages of lapped joints

Larger contact area - beneficial in joining processes employing weaker jointing consumables, e.g. brazing and adhesive bonding, and also for electrical conductivity

Readily amenable to mechanical fastening

Less accurate fit-up required - easier to assemble, therefore

Lower cost to produce

Joint type	Weld type	No. of sides (Preparation shape)	Process	Penetration	Joint preparation	Finished joint
In-line butt	Butt	Single (Vee)	Arc	Full		
In-line butt	Butt	Double (Vee)	Arc	Full		
In-line butt	Butt	Single (Close butt)	Laser	Full		
Tee	Butt	Double (Bevel)	Arc	Full		
Tee	Fillet	Double (Close butt)	Arc	None		
Lap	Fillet	Double	Arc	None		
Corner	Butt	Single (Bevel)	Arc	Partial		

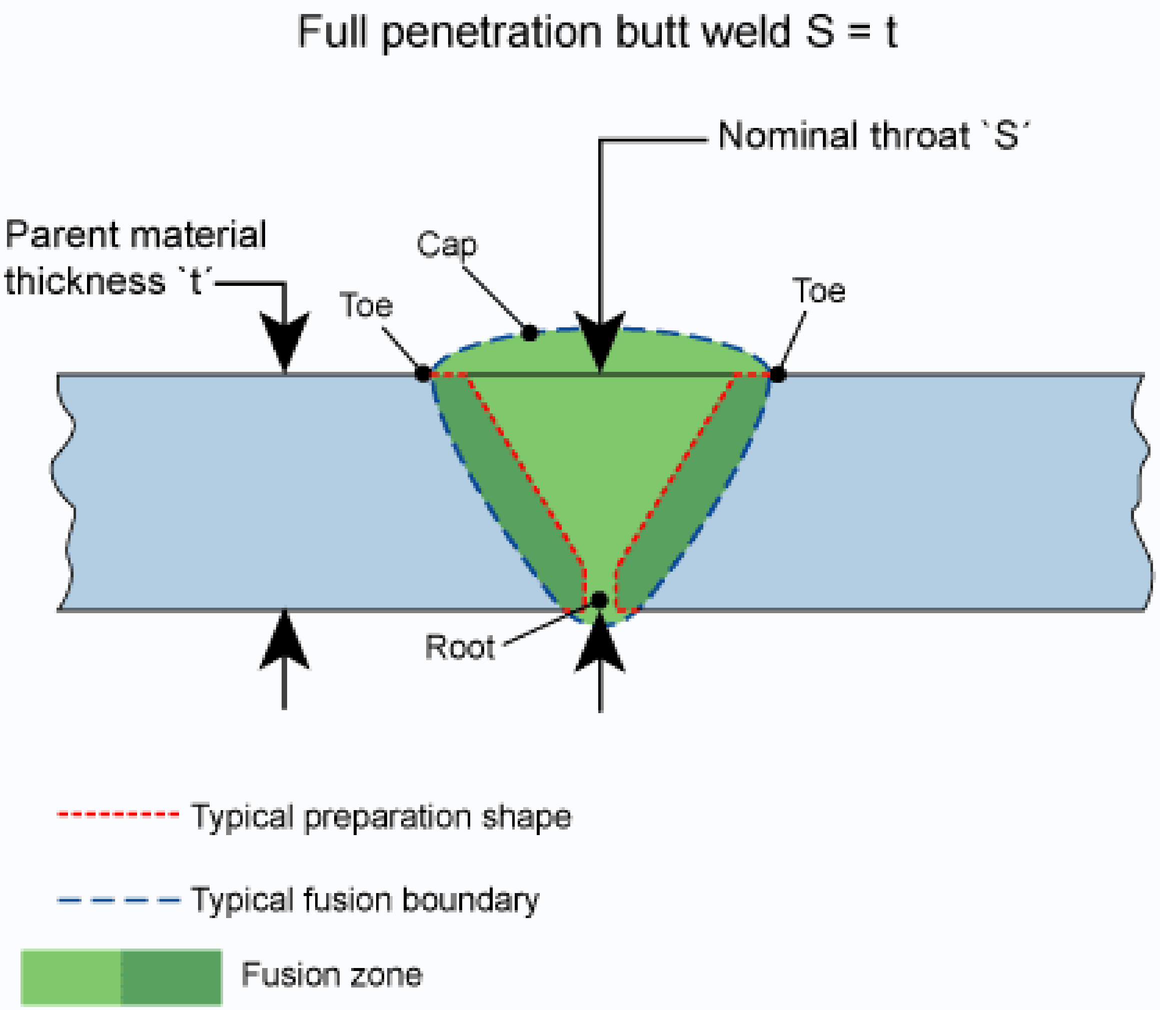
Dimensions of fusion welds: terminology, definitions, symbols and responsibilities

The most important dimension for the designer to specify is the nominal throat: 'S' for butt welds, and 'a' for fillet welds. This is defined as the shortest distance between the root and a straight line drawn between the toes. See *Fig.5*.

The root is the position of furthest penetration into the joint. The position of the root, e.g. which side of the joint and whether backing material is to be used, may affect the performance of the joint.

For a butt weld, the throat is equal to the penetration depth, either 'full' or 'partial'.

Fig.5a)



Full penetration butt weld S = t
Nominal throat `S´
Parent material
thickness `t´
Cap
Toe
Toe
Root
Typical preparation shape
Typical fusion boundary
Fusion zone

Fig.5b)

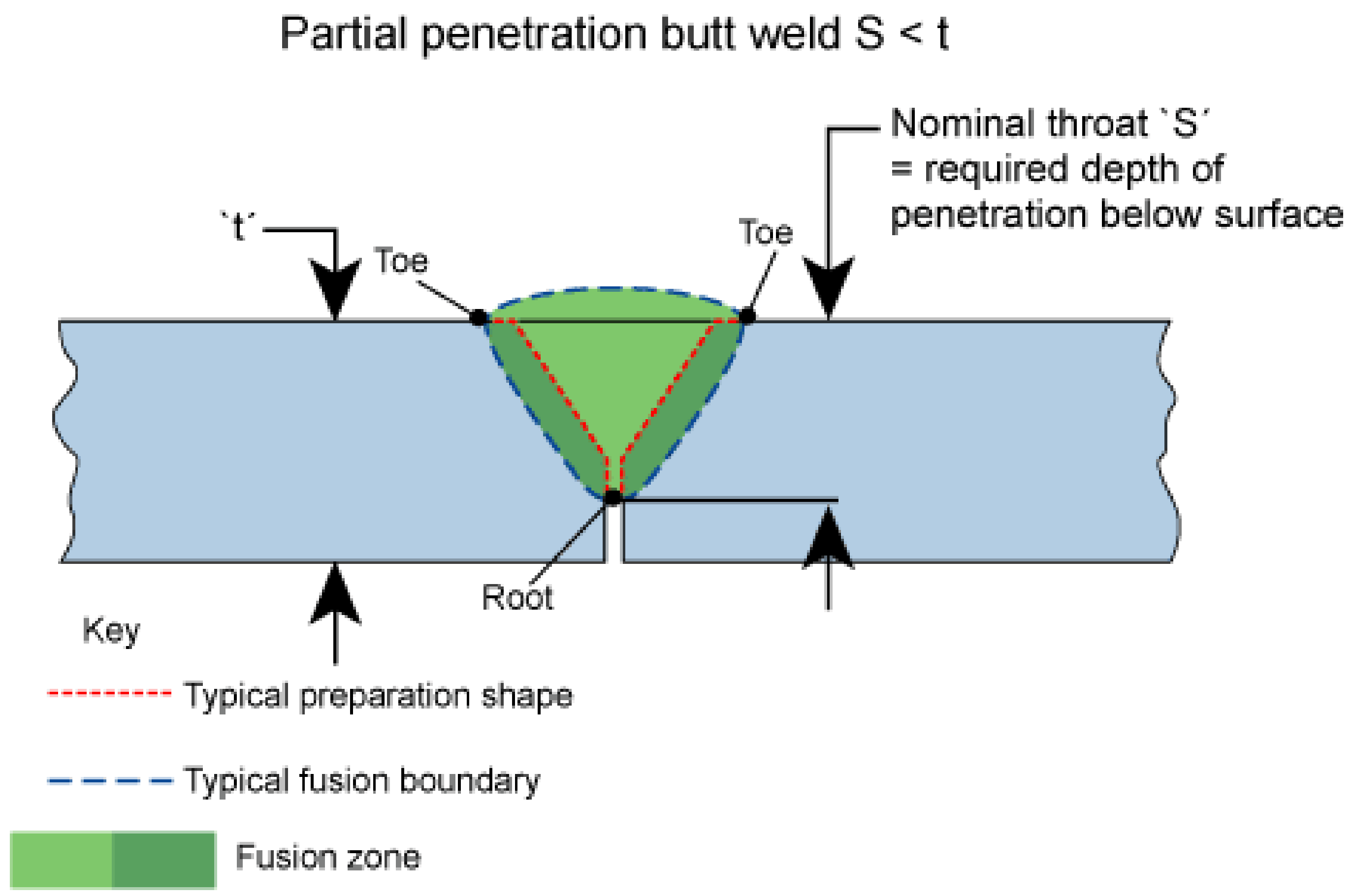

Partial penetration butt weld S < t
Nominal throat `S´
= required depth of
penetration below surface
`t´
Toe
Toe
Root
Key
Typical preparation shape
Typical fusion boundary
Fusion zone

Fig.6. Fillet weld dimensions and symbols

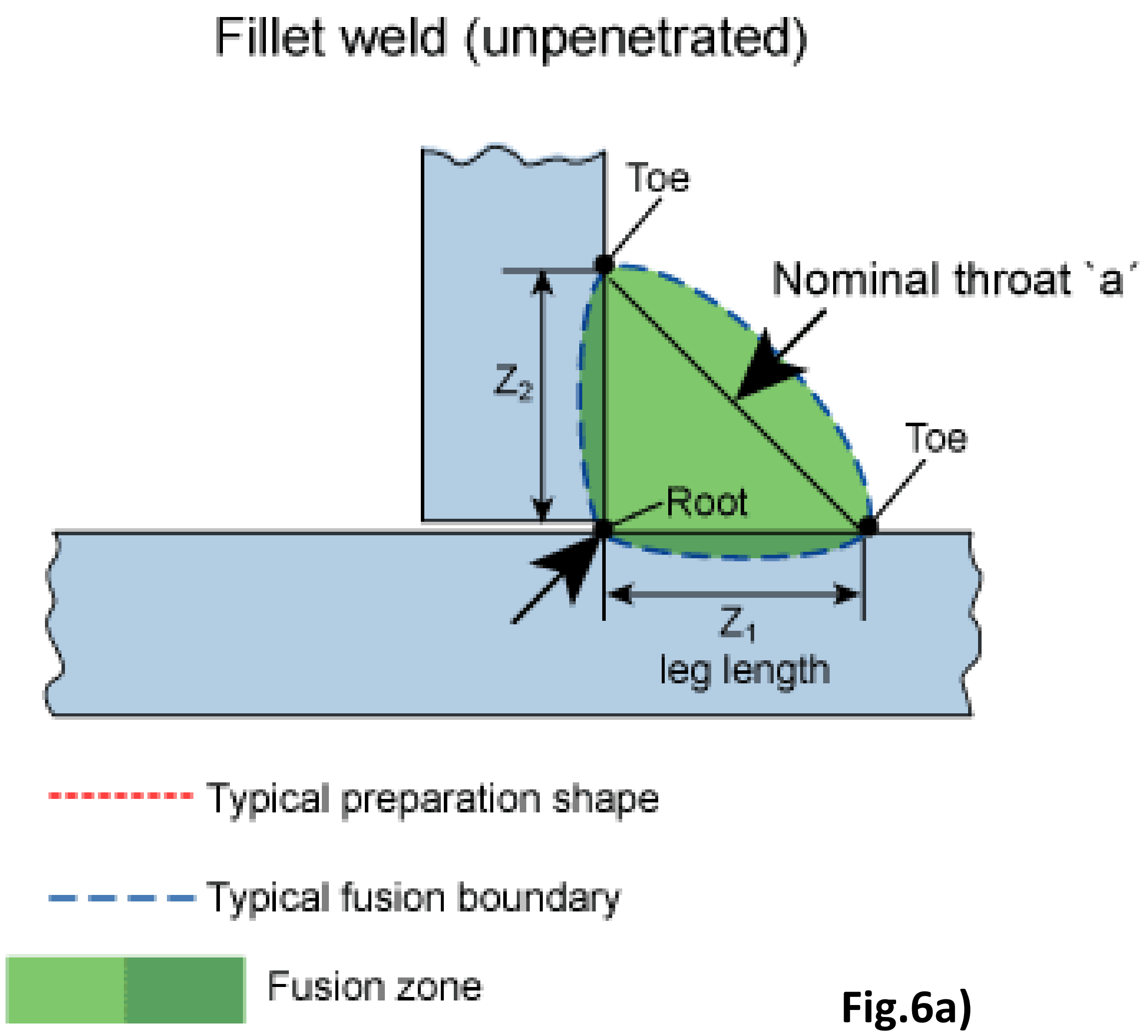
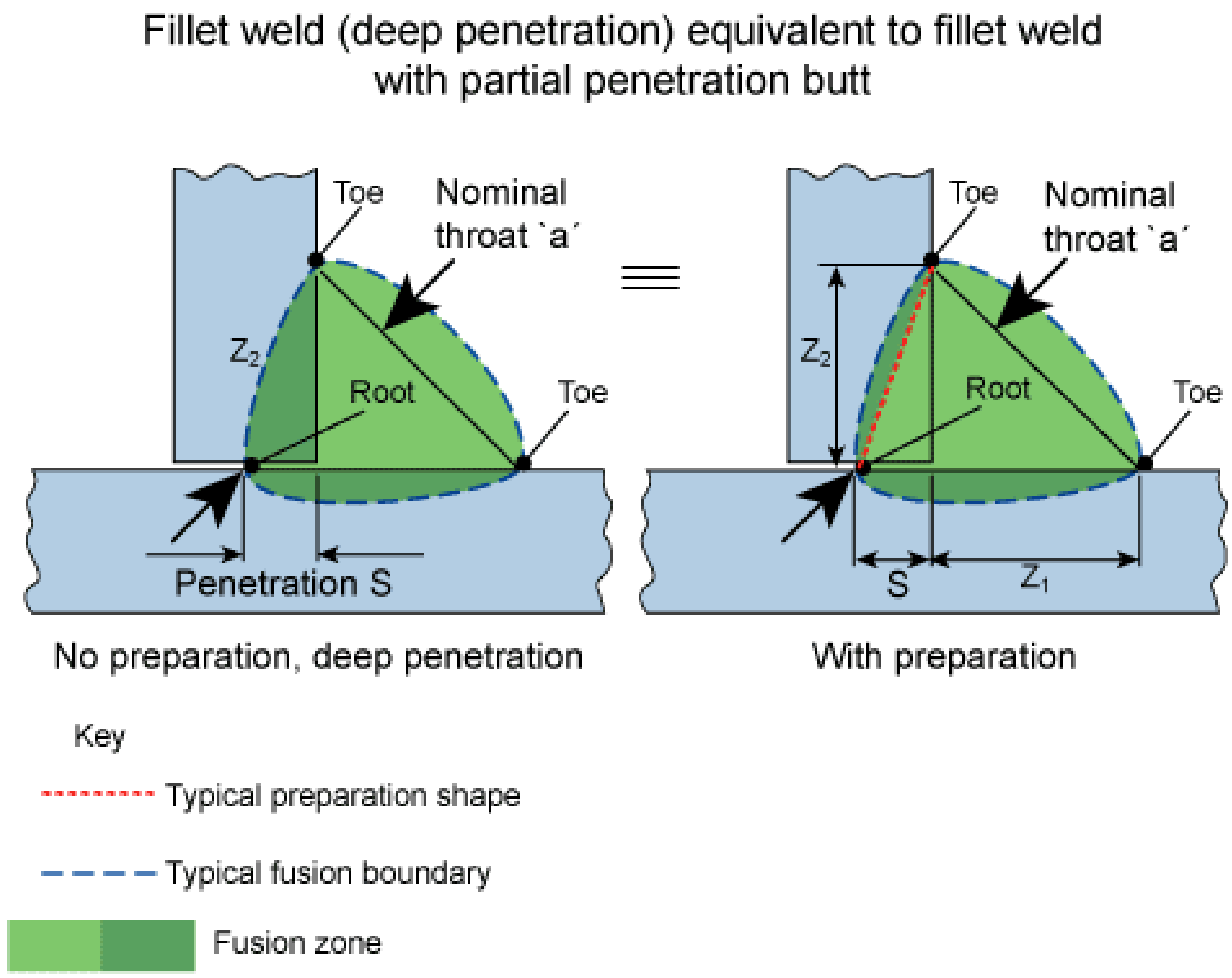


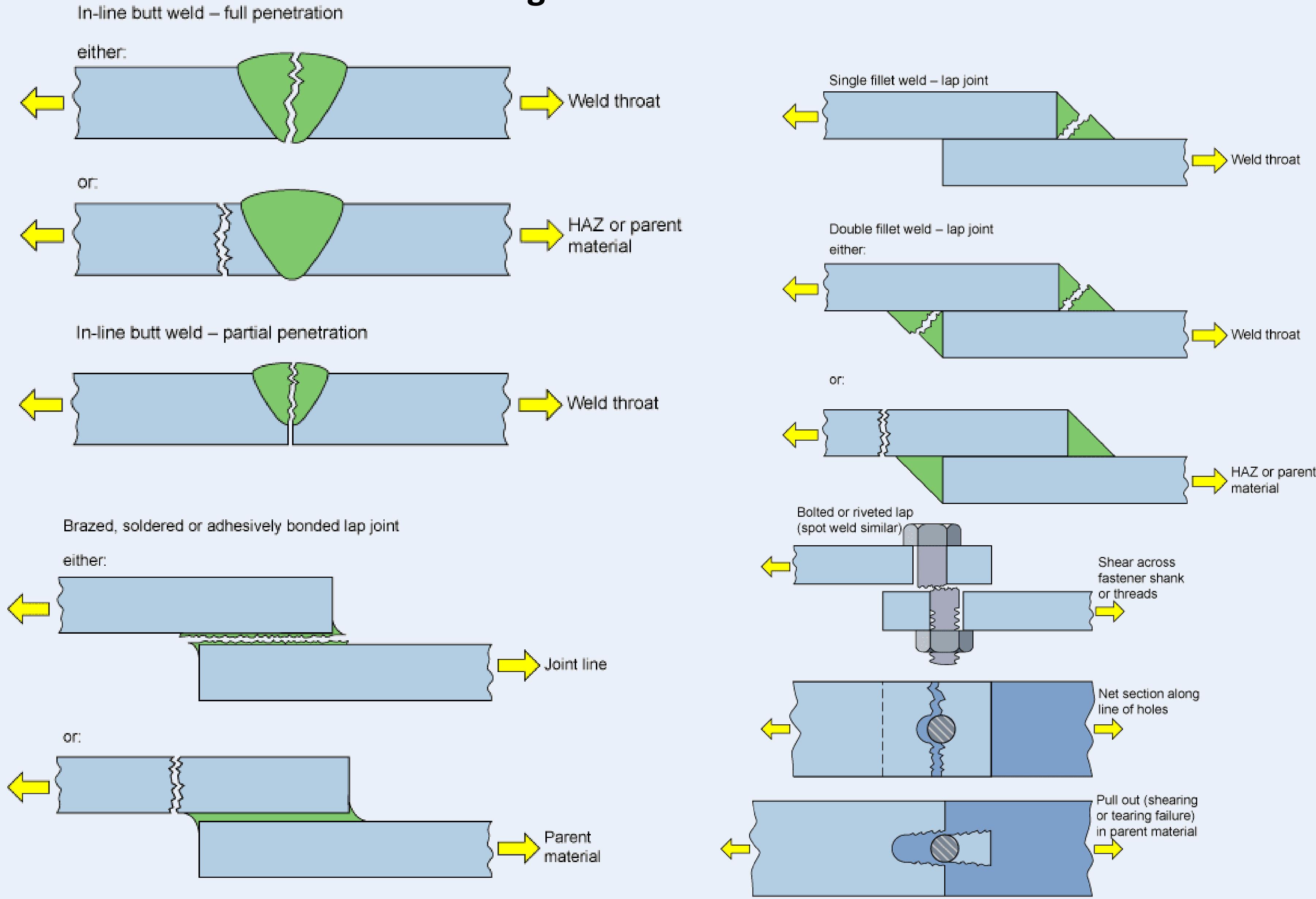
Fig.6a)

Fig.6b)



Fillet weld (deep penetration) equivalent to fillet weld
with partial penetration butt
Toe
Nominal
throat `a´
Z2
Root
Toe
Penetration S
No preparation, deep penetration
Toe
Nominal
throat `a´
Z2
Root
Toe
S
Z1
With preparation
Key
Typical preparation shape
Typical fusion boundary
Fusion zone

Fig.7. Common modes of failure



Fatigue

Fatigue will only occur if there are a sufficient number of stress fluctuations (stress ranges) of a sufficient magnitude during the design life. Applications particularly at risk are:

Rotating or reciprocating machinery

Lifting equipment

Road and rail vehicles

Ships and offshore structures

Earth-moving and mining equipment

Aircraft

Hydraulic control equipment

Bridges

Structures predominantly loaded by wind

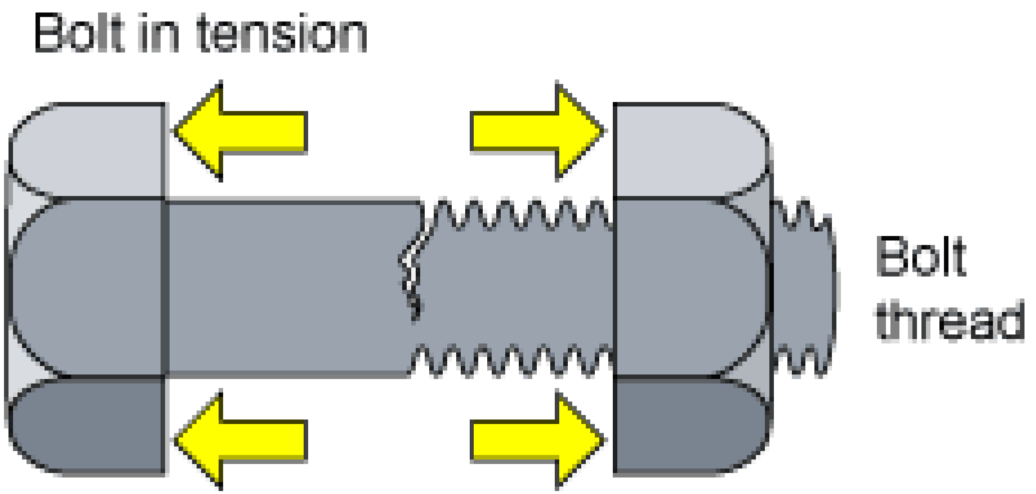
Fatigue involves the initiation of cracks at points of severe stress concentration, which then propagate under cyclic stressing until there is insufficient cross-section left to carry the static forces on the joint.

The art of fatigue design is to detail the joint so as to avoid severe stress concentrations.

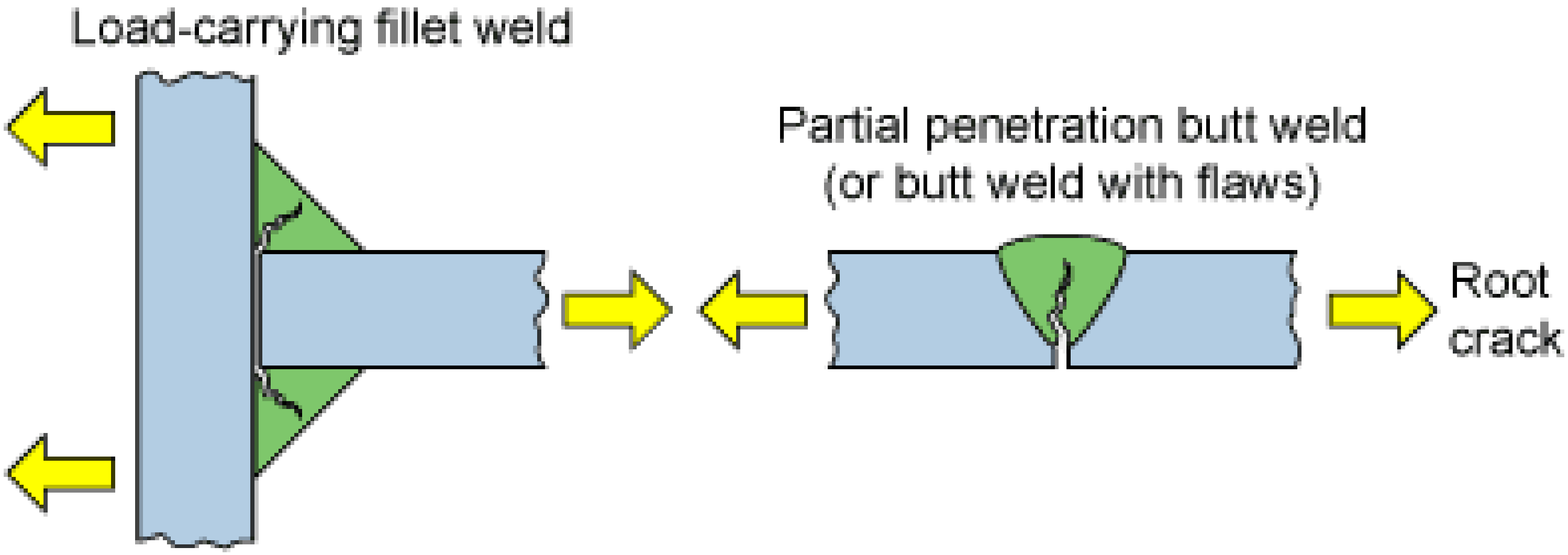
The following slides show fatigue initiation sites and directions of crack propagation for commonly-used joint types.

Bolt thread

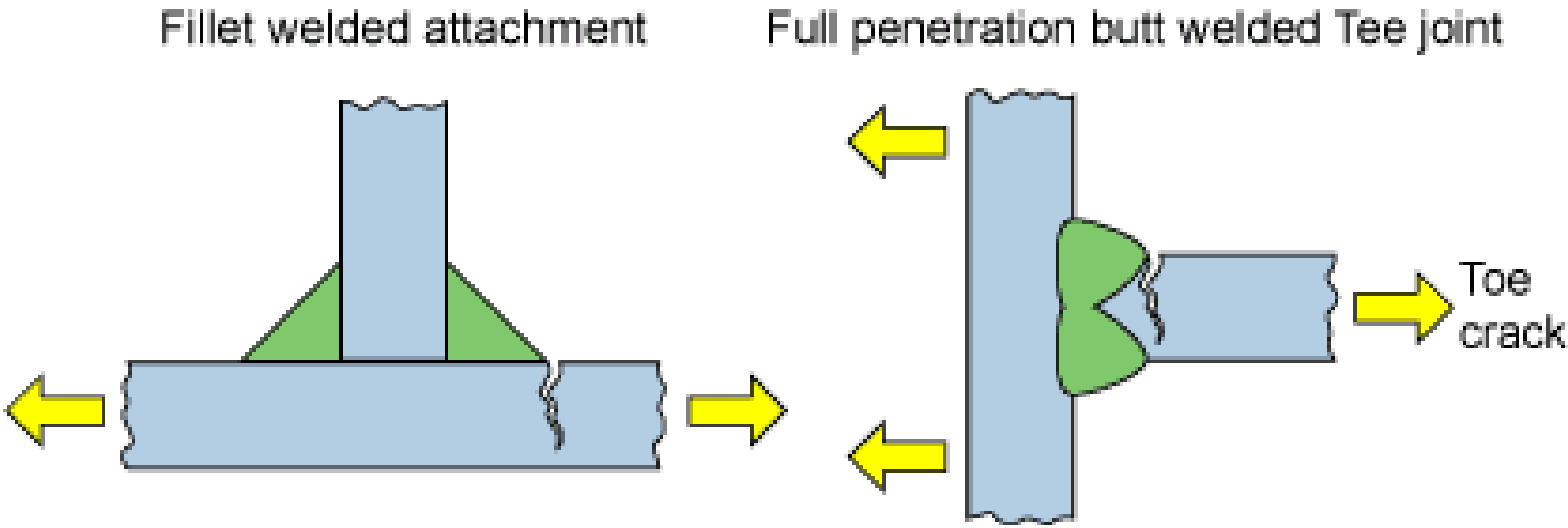
<u>Fatigue limit</u>
Static strength **(typical % for steel – approximate only) 3-7**



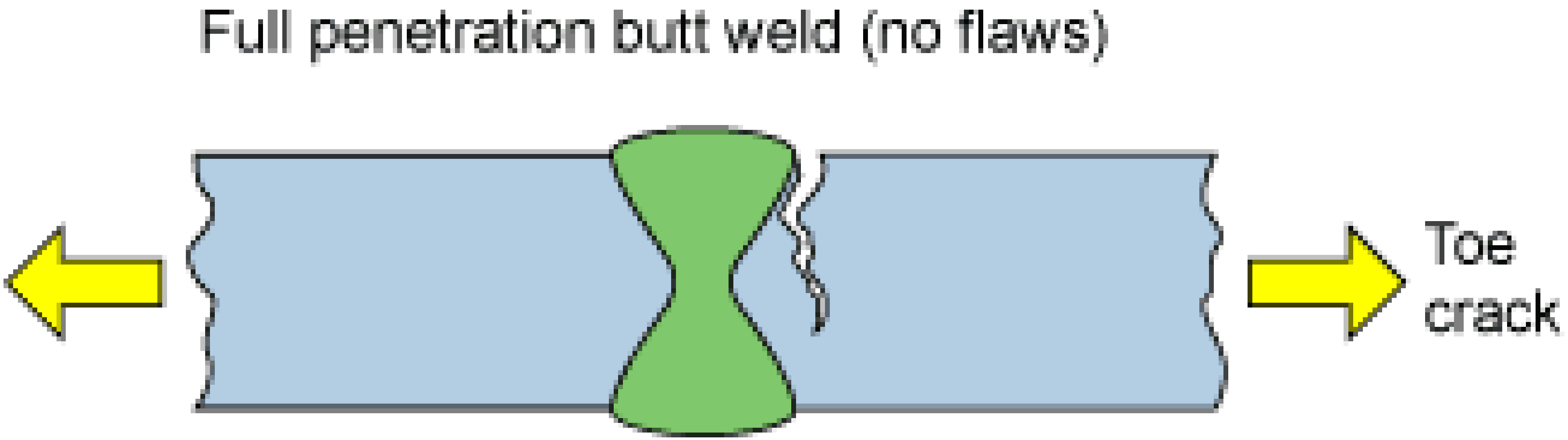
Root crack   3-7%



Toe crack 4-10%

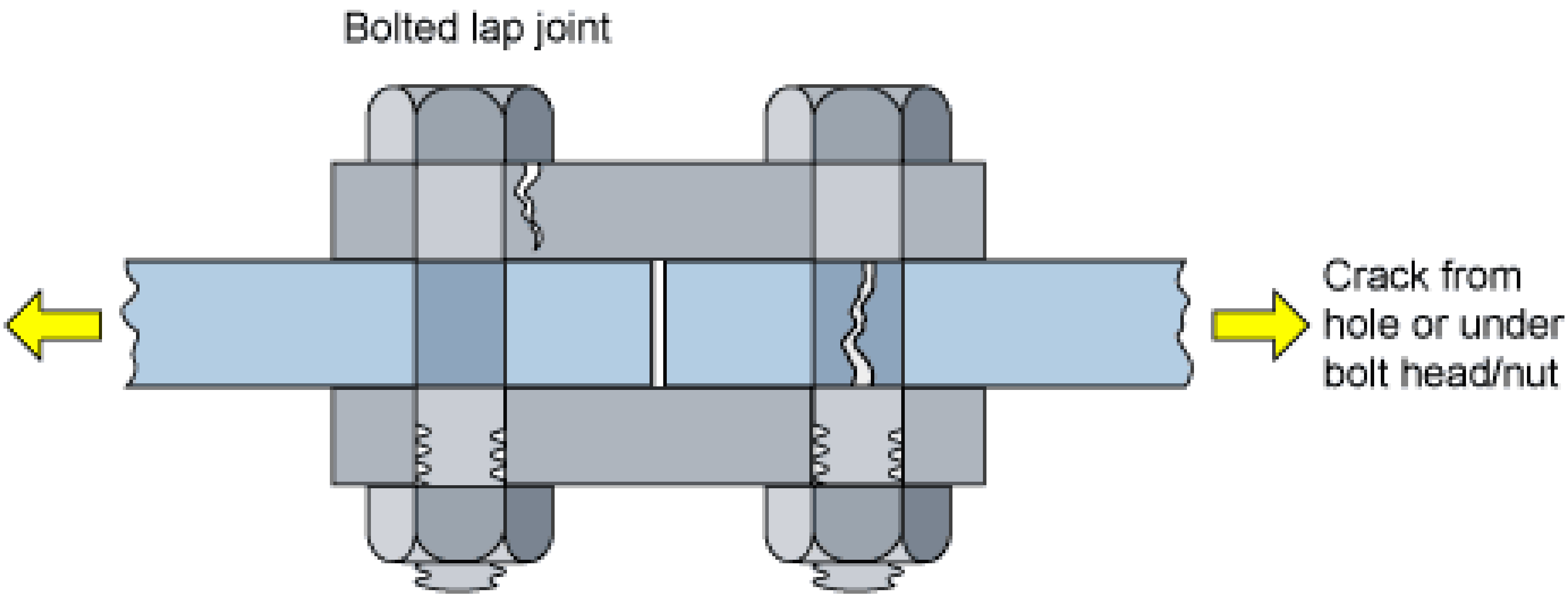


Toe crack 8-20%

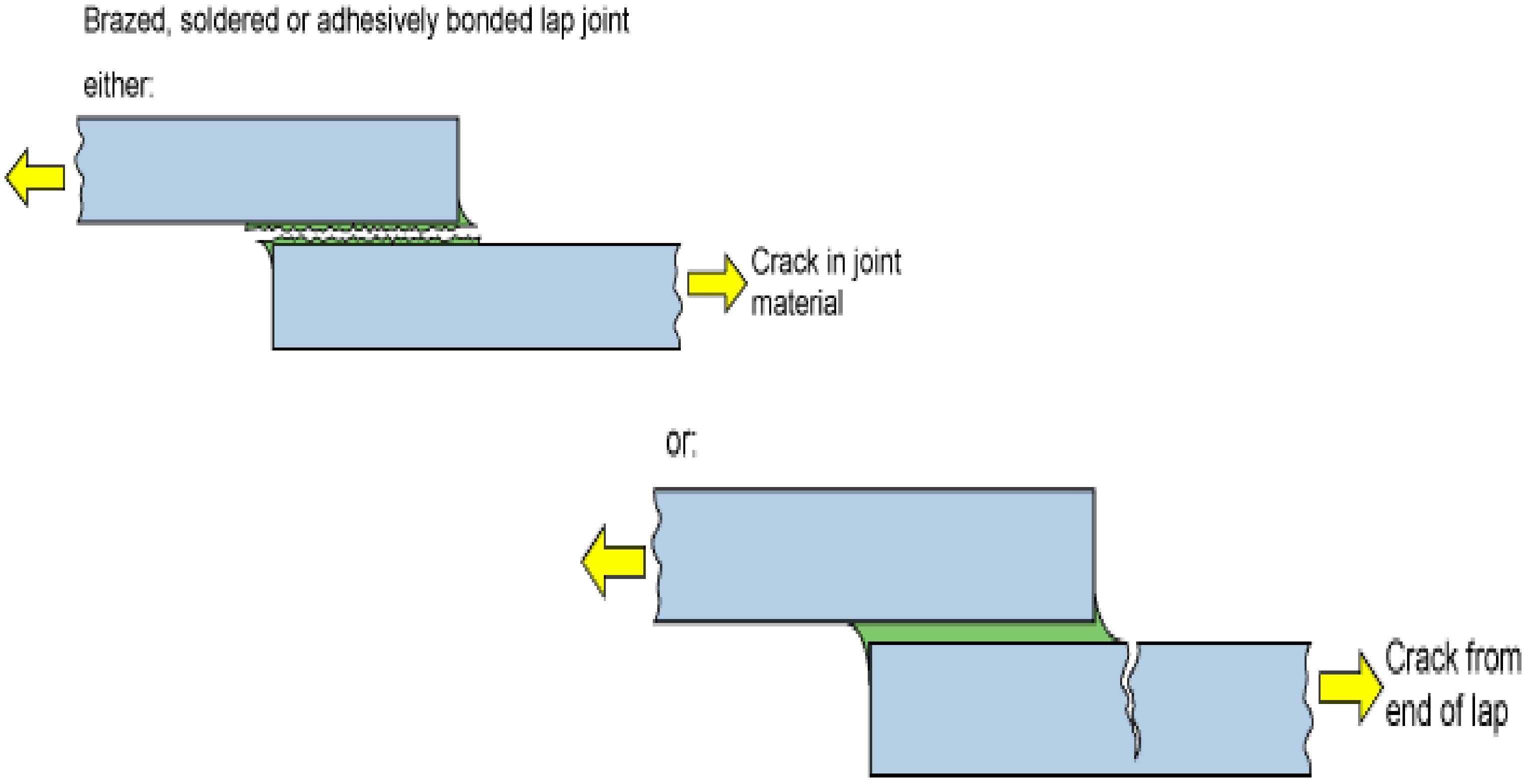


Crack from hole or under bolt head/nut

Light hand tight 5% - full torque 20%



Crack in joint material 15-35%



Methods for testing and inspection in production

General principles

Choose the most efficient, reliable and cost-effective methods for checking the most likely shortfalls in the joint in question. For mass production of low cost components, it may be best to perform random joint tests to destruction, if their static load carrying capacity is the key service requirement (see Destructive testing).

For larger components where the cost of destructive testing is prohibitive, non-destructive testing is usually employed

(see Non-destructive inspection).

Destructive testing

When static strength is a dominant design requirement, simple test jigs can be made to simulate the type of loading experienced in service (e.g. tension, shear, bending).

Destructive testing can also be used to 'open up' the joint to expose any internal manufacturing flaws which may not be detectable by other means.

Fatigue testing is usually too time-consuming for production control, but is often used for prototype testing (see BS 8118).

Non-destructive inspection

Non-destructive inspection includes visual inspection, dimensional measurement and enhanced methods for detecting surface or internal flaws (usually referred to as non-destructive testing - NDT).

The most commonly used methods of NDT are shown in *Table 8*.

Surface methods are used for detecting tight cracks, lack of fusion, etc, which are difficult to see on the surface with the naked eye.

Volumetric methods are for detecting internal cracks, voids, inadequate penetration and fusion, unbonded areas, etc, which are buried below the surface.

Location	Method	Limitations	Skill and training required
Surface	Penetrant dye	Slow	Low
	Magnetic particle	Magnetic materials only	Medium
	Eddy current	Conducting metals only	Medium
Volumetric	Ultrasonics	Best for fine-grained, homogeneous materials (not composites)	High
	Radiography	Mainly metals; best for voids, not tight cracks. Safety hazards.	High