

# 7. Welding

## 7.1 Introduction

### 7.1.1 PRINCIPLES FOR ECONOMY

The aim of weld design should be to provide the necessary structural performance throughout the lifetime of the structure for the lowest completed cost. To achieve this attention must be given to:

- (a) Economical design and detailing.
- (b) Good welding procedure and correct process selection.
- (c) Responsible inspection.

The design and detailing will greatly dictate whether or not an economical welded connection can be produced and consequently is one area where great attention should be paid. Whereas the selection of the welding procedure and process to be used is the province of the fabricator, the detailing of the welded connection can often influence or limit the range of options available. Consequently, the design and detailing of the welded connection must have some regard to the processes and procedures available if an economical welded connection is to result. Responsible inspection is also a vital item in keeping the final cost to a minimum.

The design engineer can best approach the objective of obtaining, at least cost, a safe welded steel structure or connection by considering the following influences during the design:

- Available welding processes that might be used
- Welding consumable selection
- Code requirements (AS 4100, AS 1554)
- Joint details and type of weld
- Size of weld
- Whether to use shop or field welds
- Accessibility
- Responsible specification
- Inspection

### 7.1.2 COST COMPONENTS

The cost of welding can be considered as follows, where:

$$\text{Cost of actual welding} = \frac{\text{Length of Weld} \times A \times B}{C}$$

$$A = \frac{\text{Time to weld per unit length}}{\text{Weld Volume}} = \frac{1}{\text{Deposition Rate}}$$

$$B = \frac{\text{Cost per hour}}{\text{Labour rate plus oncosts}}$$

$$C = \frac{\text{Operating Factor}}{\text{Actual Arc Time}} = \frac{1}{\text{Total Time}}$$

Total Time = includes handling, set-up, tack welding, final welding, inspection, etc.

These relationships indicate that a designer or detailer can minimise the cost of welding by attention to the following items:

- Minimising weld volume.
- Allowing for the use of high deposition rate processes; in some connections, the detailing can restrict the use of a particular process thus forcing the fabricator to use a less efficient process.
- Considering other factors which influence the deposition rate. For example, downhand welding is far more productive than overhead or vertical welding, so that details should be oriented for downhand welding wherever practicable.
- Using clean and simple detailing to assist in maintaining as high an operating factor as possible.
- Aiming to permit as much welding in the shop as possible, because the cost per hour and the operating factor are both more favourable in the shop than in the field.
- Selecting the material grade to assist in eliminating or minimising the costs of preheating or post weld treatment.

## 7.2 Types of Welds

### 7.2.1 FILLET WELDS (SEE FIGURE 7.1)

The features of fillet welds are:

- (a) Economically attractive up to 12-16 mm leg size.
- (b) Minimum edge preparation.
- (c) Easy fit-up without tight tolerances.
- (d) Poorer load carrying capacity than equivalent complete penetration butt weld and poorer fatigue characteristics. When fillet welds do not have the required load capacity, it is recommended that a partial penetration butt weld be considered rather than automatically adopting a full penetration butt weld.
- (e) Intermittent fillet welds are permitted but these are usually only economical for limited applications involving the use of manual or semi-automatic processes; in many applications, a full length fillet weld of one size may be placed more economically using a fully or semi-automatic process.
- (f) In the horizontal-vee (HV) fillet position, up to 8mm fillet sizes may be placed in a single pass using manual metal arc processes; with other processes (semi-automatic or automatic) a larger single pass fillet weld is possible. Such processes are now commonly used.
- (g) If more than a single pass fillet weld is used, the cost of the weld can increase significantly.



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The cross-sectional area of a fillet weld varies as the square of the leg size while the strength of a fillet weld (which is based on the effective throat) varies only linearly with the leg size. As indicated in Table 7.1, there is a heavy cost penalty in over-welding.

Automatic processes can reduce the cost of a fillet weld since, in addition to improving productivity, the increased penetration allows a reduced leg size for the same throat thickness.

**TABLE 7.1: Fillet weld comparison**

Fillet size (mm)	Weld strength relative to 4mm size	Weld area relative to 4mm size	Increase in weld strength for next size (%)	Increase in weld area for next size (%)
4	1.00	1.00	25	56
5	1.25	1.56	20	44
6	1.50	2.25	33	78
8	2.00	4.00	25	56
10	2.50	6.25	20	44
12	3.00	9.00	33	78
16	4.00	16.00		

## 7.2.2 BUTT WELDS (SEE FIGURE 7.2)

Two forms of butt weld are permitted in AS 1554 and AS 4100:

- Complete penetration – used where the full strength of the connected parts is required. Such a joint is given the full strength of the joined components.
- Partial penetration – used where less than full strength is acceptable, such as in low stress areas. These welds are less costly than complete penetration, although attention is needed to ensure that the specified depth of penetration is achieved in practice. These welds are permitted to carry only shear and compression loads and have low ratings for fatigue conditions.

Typical details of both types are shown in Figure 7.2.

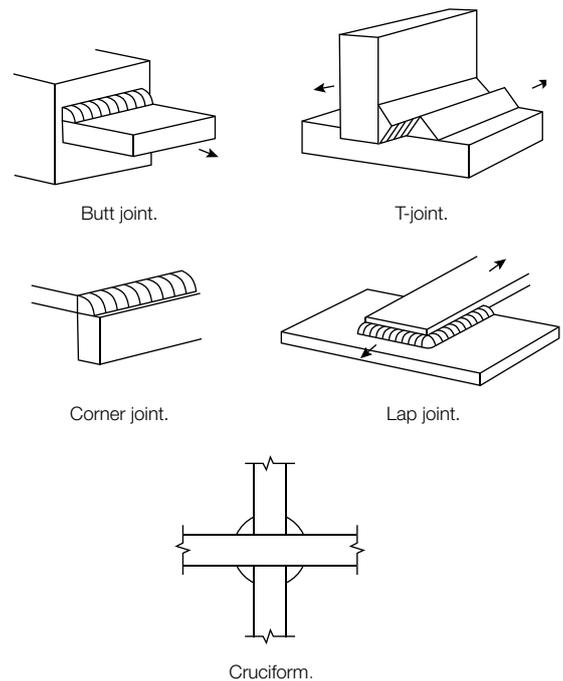
Butt welds usually require special edge preparation which (depending on the preparation type and the cutting practice) can add to the cost. Types of edge preparation normally in use are:

- Square (no special preparation)
- Single or double bevel
- Single or double V
- Single or double J
- Single or double U

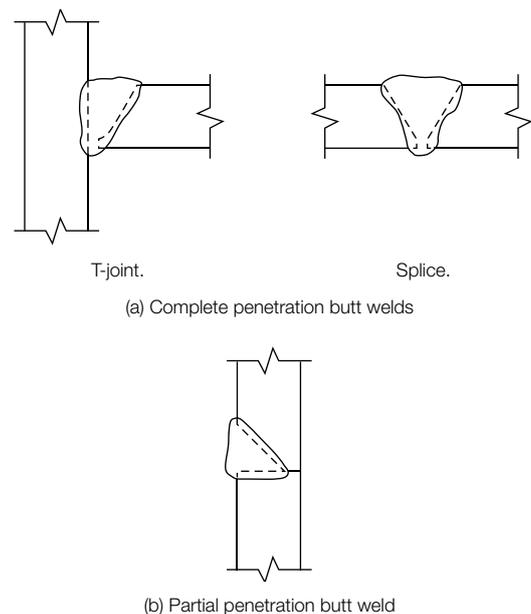
When selecting joint preparations for butt welds, prequalified preparations should be used wherever

possible to obviate the need for qualification testing of the weld geometry.

In selecting the included angle in a butt weld preparation, it has been demonstrated that, in general terms, the smaller the included angle in the preparation the less is the weld volume (Ref. 7.2). There is a need to temper this provision with a consideration for leaving sufficient angle for electrode access – the requirements will vary between processes.



**FIGURE 7.1: Types of fillet welds**



**Figure 7.2: Types of butt welds**

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It is therefore probably better for the design engineer to specify the requirements (e.g. 'complete penetration butt weld' or 'partial penetration butt weld, depth of penetration 12mm') and allow the fabricator to select the best weld geometry/welding process combination to achieve the desired result. All such proposals can be submitted to the designer for approval if necessary.

## 7.2.3 BUTT WELDS VS. FILLET WELDS

It is important to note that the volume of weld metal in a butt weld (partial penetration or complete penetration) depends on the type of preparation used as well as the depth of penetration. In contrast, the fillet weld increases in weld volume as the square of the leg size.

In comparing the relative costs of butt welds and fillet welds, these differing relationships should be borne in mind, in addition to the fact that the butt weld usually requires edge preparation while the fillet weld does not.

The relative economics of the two will depend on the application and on the fabricator's equipment and methods, and it is quite feasible for individual fabricators to cost various sizes of both types and plot a graph which will look something like Figure 7.3. The crossover point of weld size below which a fillet weld is the cheaper solution lies generally in the range 12-16 mm for many applications. Further information on the relative cost of fillet and butt welds can be found in Section 10 of Ref. 7.3.

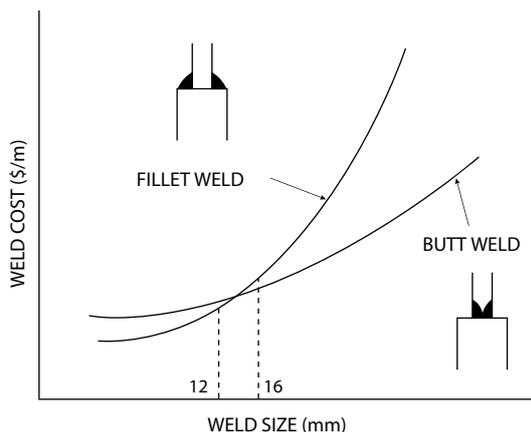


FIGURE 7.3: Weld cost graph

## 7.3 Welding Processes

The welding processes of interest in the welding of structural steel are:

- Manual metal arc (MMAW)
- Flux cored arc (FCAW)
- Gas shielded metal arc (GMAW)
- Submerged arc (SAW)
- Electroslag (ESW)
- Stud welding

For efficient design, it is necessary to understand the basic features of each welding process, to know its advantages and disadvantages and to understand the implication that the design can have on process selection, since it is necessary that a design is realistic in terms of both weld cost and weld quality.

Manual metal arc welding ('stick electrode' welding) is the simplest and most flexible of all the processes and is suitable for welding in all positions both in the shop and in the field. However, it is capable of only low deposition rates and has an intrinsically poor productivity because of the stop-start nature of the process. It is gradually being superseded by more efficient and economic continuous wire processes.

Flux cored arc welding employs a continuous hollow electrode which contains the flux. It is capable of relatively high deposition rates, is suitable for all positions and in its gasless form is ideal for field welding.

Gas metal arc welding uses a continuous solid wire electrode shielded by inert gas. It too is a high productivity flexible process and is replacing manual metal arc welding in many fabrication shops.

Submerged arc welding is another continuous wire process, where the arc is submerged under a layer of flux. It is essentially a very high deposition method intended for automatic or semi-automatic set-ups in the shop; automatic machines for welding plate girders use this process. Some specialised field applications have also been developed.

Electroslag welding is a special automatic process normally used by the larger fabricators to butt weld plates. It is a single pass vertical process and is economic for plates 25mm thick and above.

Stud welding uses special equipment for the attachment of shear studs to steel members in composite construction. It is a portable process suitable for field use, but can be readily adapted to an automatic or semi-automatic set-up in the shop.

These welding processes are described in greater detail in Ref. 7.1.

There can be startling savings in the cost of welds produced by the more modern processes. For example, considering a 6mm downhand fillet weld made by manual welding using traditional rutile electrodes, the cost can be halved if iron powder electrodes are employed. This cost in turn can be halved again by adopting a suitable continuous wire process.

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