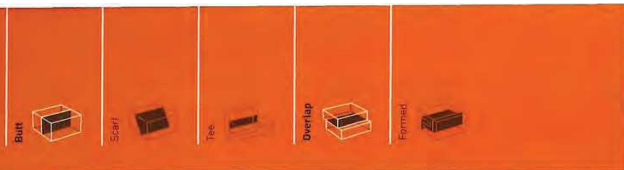


Joining Technology

Friction Welding

Forge welding processes are used to form permanent joints in metals. There are 4 main techniques: rotary friction welding (RFW), linear friction welding (LFW), orbital friction welding (OFW) and friction stir welding (FSW).

Costs	Typical Applications	Suitability
• RFW, LFW and OFW: No tooling costs • FSW: Inexpensive tooling costs • Low to moderate unit costs	• Aerospace • Automotive and transportation • Shipbuilding	• High volume production
Quality	**Related Processes**	**Speed**
• High integrity hermetic seal • High strength joint that can have similar characteristics to base material	• Arc welding • Power beam welding • Resistance welding	• Rapid cycle time that depends on size of joint

INTRODUCTION

The 4 main friction welding techniques can be separated into 2 groups: conventional techniques including LFW, OFW and RFW processes; and a recent derivative, FSW.

LFW, OFW and RFW operations weld materials with frictional heat generated by rubbing the joint interface together. The joint plasticizes and axial pressure is applied, forcing the materials to coalesce. The rotary technique (see main image) was the earliest and is the most common of the friction welding techniques.

In FSW the weld is formed by a rotating non-consumable probe (tool), which progresses along the joint mixing the material at the interface (see image, page 396, above left).

TYPICAL APPLICATIONS

Application of these processes is concentrated in the automotive, transportation, shipbuilding and aerospace industries.

In the automotive industry, RFW is used for critical parts including drive shafts, axles and gears. LFW is utilized to join engine parts, brake discs and wheel rims. OFW has not yet found commercial application in metals, but is utilized in the plastics industry (see vibration welding, page 298). FSW is used to join flat panels, formed sheets, alloy wheels, fuel tanks and space frames.

The first commercial application of FSW was in the shipbuilding industry, for welding extruded aluminium profiles into large structural panels. This has benefits for many industries: for example, the railway one, in the construction of prefabricated structural components in train carriages (see images, page 297, above, top right and above right). FSW is suitable as it causes very little distortion in the welded parts, even across long joints in thin sections.

Recently, FSW has been introduced into the consumer electronics industry, such as in the fabrication of Bang & Olufsen aluminium speakers (see images, page 297, above left and left).

RELATED PROCESSES

Even though the welds are of similar quality, friction welding is not as widely used as arc welding (page 282) and resistance welding (page 308). This is mainly because it is a more recent development: for example, TWI patented friction stir welding only in 1991. It is also because friction welding is a specialized technique, and the equipment costs are extremely high.

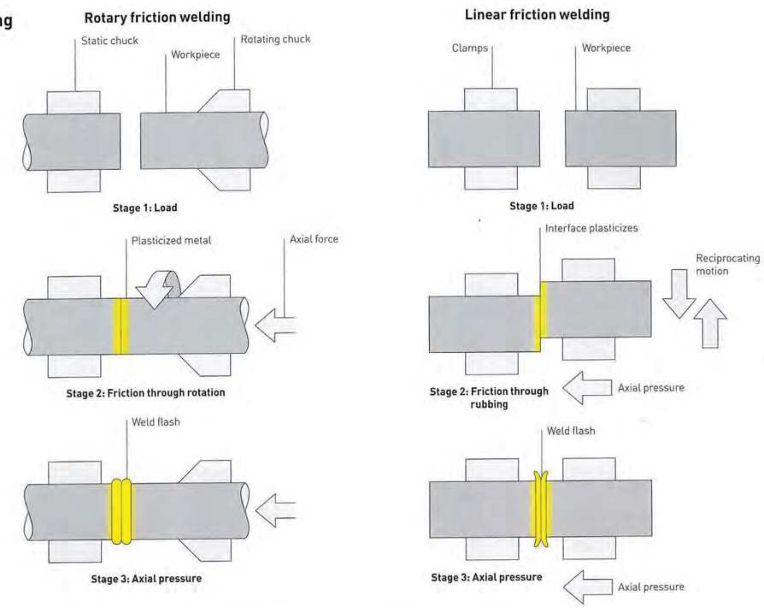
Friction welding does not take the weld zone above melting point, so this process can join metals that are not suitable for fusion welding by arc or power beam welding (page 288).

Friction welding plastics is known as vibration welding (page 298).

QUALITY

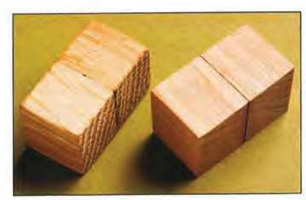
Friction welding produces high integrity welds. Butt joints are fused across the

Friction Welding Processes



Above
This titanium blisk (1-piece bladed disc) for jet engines is made by linear friction welding.

Right
These beech blocks have been joined by linear friction welding.



TECHNICAL DESCRIPTION

The use of RFW is limited to parts where at least 1 part is symmetrical around an axis of rotation. In stage 1, the 2 workpieces are secured onto the chucks. In stage 2, 1 of the parts is spun while the other is stationary. They are forced together, and friction between the 2 faces causes the metal to heat up and plasticize. In stage 3, after a specified time – a minute or so – the spinning stops and the axial force is increased to 20 tonnes or so. Flash forms around the circumference of the joint and can be polished off afterwards.

Another technique uses stored energy and is known as inertia friction welding. In this process the spinning workpiece is attached to a flywheel. Once up to speed, the flywheel is left to spin freely. The parts are brought together and the stored energy in the flywheel spins the parts sufficiently for a weld to form. The process is similar to RFW, except that a mandrel is used to maintain the internal diameter of the pipe.

LFW and OFW are based on the same principles as RFW. However, instead of rotation, the parts are oscillated against one another. In stage 1, the 2 workpieces are clamped. In stage 2, the joint interface is heated by rubbing the parts together. In stage 3, axial force is increased and maintained until the joint has formed.

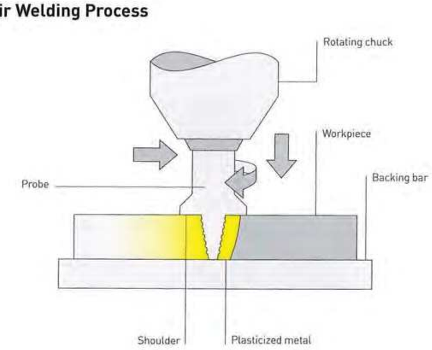
LFW typically operates at frequencies up to 75 Hz and amplitudes of ±3 mm (0.118 in.). These processes were developed for parts that are not suitable for rotary techniques.

TECHNICAL DESCRIPTION
This process is similar to RFW, LFW and OFW because the metals are welded by mixing the joint interface. Likewise, there is no consumable wire, shielding gas or flux. However, FSW differs from the other friction welding techniques because it uses a non-consumable probe to mix the metals.

The probe is rotated in a chuck at high speed, pushed into the joint line and progresses along the joint interface, plasticizing material that comes into contact with it. The probe softens the material, while the shoulder and backing bar prevent the plasticized metal from spreading. As the probe progresses, the mixed material cools and solidifies, to produce a high integrity weld.

Even though FSW tools are non-consumable, they can run for only up to 1000 m (39.4 in.) before they need to be replaced. Some techniques run more than 1 tool in parallel, for a broader weld or for a weld from either side to form a deeper joint.

Friction Stir Welding Process



Above left
This aluminium butt joint profile is being made using friction stir welding.

Above right
The tool (probe) and butt joint have been formed in aluminium by friction stir welding.

entire joint interface. These are solid state welding processes. In other words, they weld metals below their melting point. The heat-affected zone (HAZ) is relatively small and there is very little shrinkage, and thus distortion, even in long welds.

DESIGN OPPORTUNITIES

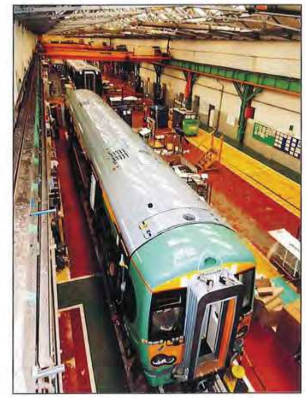
As the friction welding techniques are relatively new processes, especially FSW, many commercial opportunities have yet to be fully understood.

Friction welding offers important advantages such as the ability to join dissimilar materials without loss of weld integrity. Useful material combinations include aluminium and copper, and aluminium and stainless steel.

It is also possible to join materials of dissimilar thickness. Multiple layers stacked up can be welded in a single pass with FSW.

Use of RFW, LFW and OFW is limited to parts that can be moved relative to one another along the same joint plane. FSW, on the other hand, can be computer-guided around circumferences, complex 3D joint profiles and at any angle of operation. Combined, these processes can fuse almost any joint configuration and part geometry. FSW is also capable of producing butt, lap, tee and corner joints. It is particularly useful in the fabrication of parts that cannot be cast or extruded such as large structural panels made up of several extrusions.

These processes are not affected by gravity, and so can be carried out upside down if necessary.



Left above and left
Bang & Olufsen BeoLab aluminium speakers were designed by David Lewis and launched during 2002.

Above, top right and above right
Lightweight and structural aluminium panels, made by friction stir welding, are needed in the production of train carriages.

DESIGN CONSIDERATIONS

Because they are comparatively new, the equipment costs for friction welding are still very high. Therefore it is expensive to develop products with these processes in mind unless there are high volumes of production to justify the investment. This is partly why friction welding is used extensively in the automotive and shipbuilding industries and only to a limited extent elsewhere.

FSW is suitable for materials ranging from 1.2 mm up to 50 mm (0.047–1.97 in.) in non-ferrous metals. It is possible to weld joints up to 150 mm (5.91 in.) deep if welded from both sided simultaneously. Recently, microfriction welding techniques have been developed that are capable of welding materials down to 0.3 mm (0.012 in.).

Joint size in RFW, LFW and OFW techniques is limited to less than 2,000 mm^2 (3.1 $in.^2$).

COMPATIBLE MATERIALS

Most ferrous and non-ferrous metals can be joined in this way, including low carbon steel, stainless steel, aluminium alloys, copper, lead, titanium, magnesium and zinc. It is even possible to weld metal matrix composites.

Pipes can be joined in a process known as radial friction welding, which is a development on RFW. The difference is that in radial friction welding an internal mandrel is used to support the weld area.

Recent developments in LFW have made it possible to join certain woods, including oak and beech (see image, page 295, right). Although TWI assessed the process in 2005, it is still in the very early stages of development. In the future this process has the potential to replace conventional wood joining techniques.

COSTS

FSW requires tooling, the cost of which depends on the thickness and type of material; even so, it is inexpensive. The cost of this process is largely dependent on the equipment and development for the application.

Cycle time is rapid for RFW, LFW and OFW. FSW is the slowest of the friction welding processes because it runs along the entire length of the joint. Using FSW, 5 mm (0.2 in.) aluminium can be welded at approximately 12 mm (0.472 in.) per second. Thick materials will take considerably longer.

ENVIRONMENTAL IMPACTS

Friction welding is an energy efficient process for joining metals; there are no materials added to the joint during welding such as flux, filler wire or shielding gas. This process generates no waste; the exception is run-offs in FSW, where the weld runs from edge to edge.

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