7.

Pressure Welding
Figure 7.1 shows a survey of the **pressure welding processes** for joining of metals in accordance with DIN 1910.

In gas pressure welding a distinction is made between **open square and closed square gas pressure welding**, Figure 7.2.

Both methods use efficient gas torches to bring the workpiece ends up to the welding temperature. When the welding temperature is reached, both joining members are butt-welded by the application of axial force when a flash edge forms. The long preheating time leads to the formation of a coarse-grained structure in the joining area, therefore the welds are of low toughness values. As the process is operated mains-independently and the process equipment is low in weight and also easy to handle, the main application areas of gas pressure welding are the welding of reinforcement steels and of pipes in the building trade.

In **pressure butt welding**, the input of the necessary welding heat is produced by resistance heating. The necessary axial force is applied by copper clamping jaws which also receive the current supply, Figure 7.3. The current circuit is closed over the abutting surfaces.
of the two joining members where, by the increased interface resistance, the highest heat generation is obtained. After the welding temperature - which is lower than the melting temperature of the weld metal – is reached, upset pressure is applied and the current circuit is opened. This produces a thick flash-free upset seam which is typical for this method. In order to guarantee the uniform heating of the abutting faces, they must be conformable in their cross-sectional sizes and shapes with each other and they must have parallel faces.

As no molten metal develops during pressure upset butt welding, the joining surfaces must be free from contaminations and from oxides. Suitable for welding are unalloyed and low-alloy steels. The welding of aluminium and copper material is, because of the tendency towards oxidation and good conductivity, possible only up to a point. For the most part, smaller cross-sections with surfaces of up to 100 mm² are welded. Areas of applications are chain manufacturing and also extensions of wires in a wire drawing shop.
A **flash butt welding equipment** is, in its principal structure, similar to the pressure butt welding device, Figure 7.4.

While in pressure upset butt welding the joining members are always strongly pressed together, in flash butt welding only “fusing contact” is made during the heating phase. During the welding process, the workpiece ends are progressively advanced towards each other until they make contact at several points and the current circuit is over these contact bridges closed. As the local current density at these points is high, the heating also develops very fast. The metal is liquified and, partly, evaporated. The metal vapour pressure causes the liquified metal to be thrown out of the gap. At the same time, the metal vapour is generating a shielding gas atmosphere; that is to say, with the exception of pipe welds, welding can be carried out without the use of shielding gas.

**The constant creation and destruction of the contact bridges** causes the abutting faces to “burn”, starting from the contact points, with **heavy spray-type ejection**. Along with the occurrence of material loss, the parts are progressively advanced towards each other again. New contact bridges are created again and again. When the entire abutting face is uniformly fused, the two workpiece ends are, through a high axial force, abruptly pressed together and the welding current is switched off. This way, a narrow, sharp and, in contrast to friction welding, **irregular weld edge** is produced during the upsetting progress, which, if necessary, can be easily mechanically removed while the weld is still warm, Figure 7.5.

In flash butt welding, a fundamental distinction is made between two different working techniques. During **hot flash butt welding** a preheating operation precedes the actual flashing process, Figure 7.6. The preceding resistance heating is carried out by “reversing”, i.e., by the changing short-circuiting and pressing of the joining surfaces and by the mechani-
7. Pressure Welding

...cal separation in the reversed motion. When the joint ends are sufficiently heated, is the flashing process is initialised automatically and the following process is similar to **cold flash butt welding**. In contrast to cold flash butt welding, the advantage of hot flash butt welding is that, on one hand, sections of 20 times the size can be welded with the same machine efficiency and, on the other hand, a smaller temperature drop and with that a lower cooling rate in the workpiece can be obtained. This is of importance, especially with steels which because of their chemical composition have a tendency to harden. The cooling rate may also be reduced by conductive re-heating inside the machine.

A smooth and clean surface is not necessary with hot flash butt welding. If the abutting faces differ greatly from the desired plane-parallelism, an additional flashing process (a short flashing period with low speed and high energy) may be carried out first.

The welding area of the **structure of a flash butt weld** shows a zone which is reduced in carbon and other alloying elements, Figure 7.7. Moreover, all flash butt welded joints have a pronounced coarse grain zone, whereby the toughness properties of the welded joint are lower than of the base metal. By the impact normalizing effect in

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**Figure 7.6**

**Figure 7.7**
the machine successive to the actual welding process, can the toughness properties be considerably increased. By one or several current impulses the weld temperatures are increased by up to approximately 50° over the austenitising temperature of the metal.

Steels, aluminium, nickel and copper alloys can be welded economically with the flash butt welding process. Supported by the axial force, shrinkage in flash butt welding is so insignificant that only very low residual stresses occur. It is, therefore, possible to weld also steels with a higher carbon content.

Profiles of all kind are butt welded with this method. The method is used for large-scale manufacture and with components of equal dimensions. The weldable cross-sections may reach dimensions of up to 120,000 mm². Areas of application are the welding of rails, the manufacture of car axles, wheel rims and shafts, the welding of chain links and also the manufacture of tools and endless strips for pipe production.

**Friction welding** is a pressure welding method where the necessary heat for joining is produced by mechanical friction. The friction is, as a rule, generated by a relative motion bet-
between a rotating and a stationary workpiece while axial force is being applied at the same time, Figure 7.8.

After the joint surfaces are adequately heated, the relative motion is discontinued and the friction force is increased to upsetting force. An even, lip-shaped bead is produced which may be removed in the welding machine by an additional accessory unit. The bead is often considered as the first quality criterion.

Figure 7.9 shows all phases of the friction welding process. In most cases this method is used for rotation-symmetrical parts. It is, nowadays, also possible to accurately join rectangular and polygonal cross-sections.

The most common variant of friction welding is friction welding with a continuous drive and friction welding with a flywheel drive, Figure 7.10. In friction welding with continuous drive, the clamped-on part to be joined is kept at a constant nominal speed by a drive, while the workpiece in the sliding chuck is pressed with a defined friction force. The nominal speed is maintained until the demanded temperature profile has been achieved. Then the motor is declutched and the relative motion is neutralised by external braking. In general, the friction force is raised to upsetting force after the rotation movement has been discontinued. During flywheel friction welding, the inertia mass is raised to nominal speed,
the drive motor is declutched and the stationary workpiece is, with a defined axial force, pressed against the rotating workpiece. Welding is finished when the total kinetic energy stored in the flywheel – has been consumed by the friction processes. This is the so-called self-breaking effect of the system. The method is used when, based on metallurgical processes, extremely short welding times may be realised. Further process variants are radial friction welding, orbital friction welding, oscillation friction welding and friction surfacing. However, these process variants are until today still in the experimental stage. Recently, new developments in the field of friction stud welding – studs on plates – have been introduced.

Figure 7.11 depicts the **variation in time of the most important process parameters** in friction welding with continuous drive and flywheel friction welding. The occurring moments’ maxima may be interpreted as follows: The first maximum, at the start of the frictional contact, is explained by the formation of local fusion zones and their shearing off in the lower temperature range. The **torque** decreases as a result of the risen temperature - which again is a consequence of the increased plasticity - and of the lowered deformation resistance. The second maximum is generated during the braking phase which precedes the spindle standstill. The second maximum is explained by the increased deformation resistance at dropping temperatures. The temperature drop in the joining zone is explained by the lowered energy input – due to the **rotation-speed** decrease – and also by the augmented radial displacement of the highly heated material into the weld upset.

In friction welding with a continuous drive, the process variation “**combined friction welding**” allows the free and independent from each other selection of the braking and upsetting moments, Fig. 7.12.
In this case, the rotation-energy which has been stored in the drive motor, the spindle and also in the clamping chuck, may be totally or partially converted by self-breaking. Here, the breaking phase matches the breaking phase in flywheel welding. The use of this process variant allows the welding structures to influence each other in a positive way when many welding tasks are to be carried out. Moreover, the torque range may be accurately predetermined by the microcontroller of the braking initiator which prevents the slip-through of the workpieces in the clamping chuck.

The universal friction welding machine is in its structure similar to a turning lathe, however, for the transmission of the high axial forces, the machine structure must be considerably more rigid.

Basically, there are three types of friction welding: a) friction welding with a rotating workpiece and a translational motion of the other workpiece; b) friction welding with rotation and translational motion of one workpiece facing a stationary other workpiece, c) rotation and translation of two workpieces against a stationary intermediate piece. The remaining variations, shown in Figure 7.13, also find applications when both workpieces have to rotate in

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**Figure 7.13**

| Types of Friction Welding Processes |

| Figure 7.14 | Joint Types Obtained by Friction Welding |

<table>
<thead>
<tr>
<th>1. a) round stock with round stock before welding</th>
<th>after welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. a) round stock with round stock (different cross-sections, partially machined)</td>
<td>before welding</td>
</tr>
<tr>
<td>3. round stock with pipe before welding</td>
<td>after welding</td>
</tr>
<tr>
<td>4. pipe with pipe before welding</td>
<td>after welding</td>
</tr>
<tr>
<td>5. round material with plate before welding</td>
<td>g'd - 0,25...0,3</td>
</tr>
<tr>
<td>6. pipe with pipe before welding</td>
<td>after welding</td>
</tr>
<tr>
<td>7. round material with plate, without preparation before welding</td>
<td>after welding</td>
</tr>
<tr>
<td>8. pipe with plate, without preparation before welding</td>
<td>after welding</td>
</tr>
</tbody>
</table>
opposite direction to each other. For example, when a low diameter and, in connection with this, the low relative speeds demand the necessary heat quantity.

A survey of possible joint shapes achievable with friction welding is given in Figure 7.14. The specimen preparation of the joining members should, if possible, be carried out in a way that the heat input and the heat dissipation is equal for both members. Depending on the combination of materials can this provision facilitate the joining task considerably. The abutting surfaces should be smooth, angular and of equal dimensions. A simple saw cut is, for many applications, sufficient.

The method of heat generation causes a comparatively low joining temperature – lower than the melting temperature of the metals. This is the main reason why friction welding is the suitable method for metals and material combinations which are difficult to weld. It is also possible to weld material combinations (e.g. Cu/Al or Al/steel) which cannot be joined using other welding processes otherwise only with increased expenditure. Figure 7.15 shows a survey of possible material combinations. Many combinations have, however, not yet been tested on their suitability to friction welding. Metallurgical reasons which may reduce the friction weldability are:

1. the quantity and distribution of non-metal inclusions,
2. formation of low-melting or intermetallic phases,
3. embrittlement by gas absorption (as a rule, the costly, inert gas shielding can be dispensed with, even when welding titanium),
4. softening of hardened or precipitately-hardened materials and
5. hardening caused by too high a cooling rate.
By the adjustment of the welding parameters in respect to weld joints, can in most cases joints with good mechano-technological properties be obtained.

The secondary structure along the friction-welded joint is depicted in Figure 7.16. An extremely fine-grained structure (forge structure) develops in the joining zone region. This structure which is typical of a friction-welded joint is characterised by high strength and toughness properties.

Figure 7.16 shows a **comparison between a flash butt-welded and a friction-welded cardan shaft**. The two welds are distinguished by the size of their heat affected zone and the development of the weld upset. While in friction welding a regular, lip-shaped upset is produced, the weld flash formation in flash butt welding is narrower and sharper and also considerably more irregular. Besides, the heat affected zone during friction welding is substantially smaller than during flash butt welding.

**Friction welding machines are fully mechanized** and may well be integrated into production lines. Loading and unloading equipment, turning attachments for the preparation of the abutting surfaces and for upset removal and also storage units for complete welding programs make these machines well adaptable to automation. The machines may furthermore be equipped with
parameter supervisory systems. During welding are parameters: welding path, pressure, rotational speed, and time are governed by the desired value/actual value comparison. This allows an indirect quality control. A further complement to the retention of parameters is the torque control, however this method is costly and it cannot be used for all applications because of its structural dimensions.

Friction welding machines are mainly used in the series production and industrial mass production.

Nevertheless, these machines are also always applied when metals and material com-
7. Pressure Welding

Combinations which are difficult to weld have to be joined in a reliable and cost-effective way. With the machines that are presently used in Germany, it is possible to weld massive work-pieces in the diameter range of 0.6 up to 250 mm. For steel pipes, the maximum weldable diameter is at present approximately 900 mm, the wall thicknesses are approx. 6 mm.

Figures 7.18 to 7.20 show a selection of examples for the application of friction welding.

Figure 7.21 shows a comparison of the cost expenditure for the manufacture of a cardan shaft, carried out by forging and by friction welding, respectively. It shows that the application of the friction welding method may save approx. 20% of the production costs. This comparison is, however, not an universally valid statement as for each component a profitability evaluation must be carried out separately. The comparison is just to show that, in many applications, considerable savings can be made if the matter of the joining technology by “friction welding” could be circulated to a wider audience of design and production engineers.

Figure 7.22 shows in brief the important advantages and disadvantages of friction welding in comparison with the competitive method of flash butt welding.

Advantages:
- clean and well controllable bulging
- low heat influence on joining members
- better control of heat input
- low phase separation phenomena in the bond zone
- hot forming causes permanent recovery and recrystallisation processes in the welding area thus forming a very fine-grained structure with good toughness and strength properties (forged structure)
- low susceptibility to defects, extremely good reproducibility within a wide parameter range
- frequently shorter welding times
- more choice in the selection of weldable materials and material combinations

Disadvantages:
- torque-safe clamping necessary
- machine-determined smaller maximum weldable cross-sections
- susceptibility to non-metal inclusions
- high expenditure requested because of high manufacturing tolerances
- high capital investment for the machine
Pressure welding with magnetically impelled arc, “Magnetarc Welding”, is an arc pressure welding method for the joining of closed structural tubular shapes, Figure 7.23. The weldable wall thickness range is between 0.7 and 5 mm, the weldable diameter range between 5 and 300 mm. In “Magnetarc Welding” an arc burns between the joining surfaces and is rotated by external magnetic forces. This is achieved by a magnet coil system that produces a magnetic field.

The combined action of this magnetic field and the arc’s own magnetic field effects a tangential force to act upon the arc. The rotation of the arc heats and melts the joint surfaces. After an adequate heating operation, the two workpiece members are pressed and fused together. A regular weld upset develops which is normally not removed. The welding operation takes place under shielding gas (mainly CO₂).

The shielding gas’ function is not the protection of the weld from the surrounding atmosphere but rather a contribution towards the stabilisation of the arc. The reproducibility of the arc ignition and motion behaviour and the regularity of the weld bead are therefore improved.

The prerequisite for the application of a material in “Magnetarc Welding” is its electrical conductivity and melting behaviour. Fig-
ure 7.24 gives a survey of the material combinations which are nowadays already weldable under industrial conditions. As reason is the symmetric heat input, the subsequent upsetting of the liquid phase and the cooling off under pressure. The cracking sensitivity of the welds is, in general, relatively low. This has a positive effect, particularly when steels with a high carbon content or machining steels are welded. The joining faces of the workpieces must be free from contamination, such as rust or scale.

To obtain a defect-free weld, normally a simple saw cut is a sufficient preparation of the abutting surfaces. If special demands are put on the dimensional accuracy of the joints, the prefabrication tolerances have to be adjusted accordingly. This applies also to friction welding.

Figures 7.25 and 7.26 show several application examples of pressure welding with magnetically impelled arc.

Figure 7.27 shows a summary of the most important advantages and disadvantages of this method in comparison with the competitive methods of friction welding and flash butt welding.
In friction-stir welding a cylindrical, mandrel-like tool carries out rotating self-movements between two plates which are knocked and clamped onto a fixed backing. The resulting friction heat softens the base metal, although the melting point is not reached. The plastified material is displaced by the mandrel and transported behind the tool where a longitudinal seam develops.

The advantages of this method which is mainly used for welding of aluminium alloys is the low thermal stress of the component which allows joining with a minimum of distortion and shrinkage. Welding fumes do not develop and the addition of filler metal or shielding gases is not required.