10 – Assembly Techniques – Category II Welding, Adhesive Bonding

Spin Welding

Introduction

Rotation welding is the ideal method for making strong and tight joints between any thermoplastic parts which have symmetry of rotation. Engineers faced with the choice of either the ultrasonic or the spinwelding process will unhesitatingly prefer the latter, in view of the following advantages which it presents:

1) The investment required for identical production is lower with spinwelding than with ultrasonics. There are no special difficulties in construction the machinery from ordinary commercial machine parts, either wholly or partly in one's own workshop.
2) The process is based on physical principles which can be universally understood and mastered. Once the tools and the welding conditions have been chosen correctly, results can be optimised merely by varying one single factor, namely the speed.
3) The cost of electrical control equipment is modest, even for fully automatic welding.
4) There is much greater freedom in the design of the parts, and no need to worry about projecting edges, studs or ribs breaking off. Moulded in metal parts cannot work loose and damage any pre-assembled mechanical elements. Nor is it essential for the distribution of mass in the parts to be symmetrical or uniform, as is the case with ultrasonic welding.

If the relative position of the two components matters, then an ultrasonic or vibration welding process must be used.

But, in practice, there are often cases in which this is essential only because the component has been badly designed. Parts should, as far as possible, be designed in such a way that positioning of the two components relative to each other is unnecessary.

Basic Principles

In spinwelding, as the name implies, the heat required for welding is produced by a rotating motion, simultaneously combined with pressure, and therefore the process is suitable only for circular parts. It is of course immaterial which of the two halves is held fixed and which is rotated. If the components are of different lengths, it is better to rotate the shorter one, to keep down the length of the moving masses.

In making a selection from the methods and equipment described in detail below, the decisive factors are the geometry of the components, the anticipated output, and the possible amount of capital investment.

Because of the relatively small number of mechanical components needed, the equipment can sometimes be constructed by the user himself. In this way, serious defects in the welding process can often be pinpointed, some examples of which will be described later.

Practical Methods

The most commonly used methods can be divided roughly into two groups as follows:

Pivot Welding

During welding the device holding the rotating part is engaged with the driving shaft, the two parts being at the same time pressed together. After completion of the welding cycle, the rotating jig is disengaged from the shaft, but the pressure is kept up for a short time, depending on the type of plastic.

Inertia Welding

The energy required for welding is first stored up in a flywheel, which is accelerated up to the required speed; this flywheel also carries the jig and one of the plastic parts. Then the parts are forced together under high pressure, at which point the kinetic energy of the flywheel is converted into heat by friction, and it comes to a stop. In practice this method has proved the more suitable one, and will therefore be described in more detail.

Pivot Welding

Pivot Welding on a Lathe

Easily the simplest, but also the most cumbersome welding method in this group, pivot welding can be carried out on any suitable sized lathe. Fig. 10.01 illustrates the set-up.

One of the parts to be welded, *a*, is clamped by *b*, which may be an ordinary chuck, a self-locking chuck, a compressed air device, or any other suitable device, so long as it grips the part firmly, centres and drives it.

The spring-loaded counterpoint *c* in the tailstock must be capable of applying the required pressure, and should be able to recoil 5-10 mm. The cross-slide *d* should also, if possible, be equipped with a lever. The plastic part *a1* should have some sort of projecting rib, edge, etc., so that the stop *e* can prevent it from rotating.

The actual welding will then proceed as follows:

a) The part *a* is fixed into the clamp, and then its companion-piece *a1* is placed in position, where it is kept under pressure by the spring-loaded point.

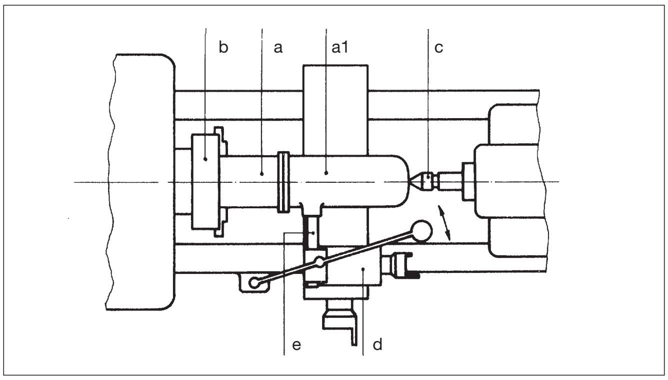


Fig. 10.01 **Pivot Welding on a Lathe**

b) The cross-slide *d* travels forward, so that the stop *e* is brought below one of the projections on *a1*.

c) The spindle is engaged or the motor switched on.

d) At the end of the welding period, the cross-slide moves back again to relase the part *a1*, which immediately begins to rotate.

e) The motor is switched off (or the spindle disengaged).

f) Pressure must be kept up by means of the spring-loaded point for a short time, the duration of which will depend on the solidification properties of the particular plastic, before the parts can be taken out.

This sequence is often made simpler by not removing the stop *e* at the end of the welding cycle, but by merely disengaging or switching off. Since, however, the moving masses in the machine are generally fairly considerable, they will not decelerate fast enough, and the weld surfaces will be subjected to shear stresses during solidification, often resulting in either low-strength or leaking joints.

In general, the narrower the melting temperature range of the plastic, the more quickly does the relative velocity of the two parts have to be reduced to zero; in other words, either the fixed partner must be rapidly accelerated, or else the rotating partner must be quickly stopped.

Using a lathe for spinwelding is not really a production method, but it can be used sometimes for prototypes or pre-production runs. It is, however, a very good way of welding caps and threated nipples onto the end of long tubes. For this purpose the tailstock is replaced by a spring-loaded jig which grips the tube and at the same time exerts pressure on it; although the lathe needs to be fitted with a clutch and a quick-acting brake, because a long tube cannot be released and allowed to spin.

Pivot Welding on Drilling Machines

Components up to 60 mm in diameter can very easily be welded on table-type drilling machines with special-purpose tools. This is the most suitable method for pre-production runs, hand-machined prototypes, or repair jobs. The process can be made fully automatic, but this is not sufficiently economical to be worthwhile. Some practice is needed to obtain uniform welds, because the welding times and pressures are influenced by the human factor.

The tool shown in Fig. 10.02 has an interchangeable tooth crown a whose diameter must match that of the plastic part. With a set of three or four such crowns it is possible to weld parts ranging from about 12 to 60 mm in diameter.

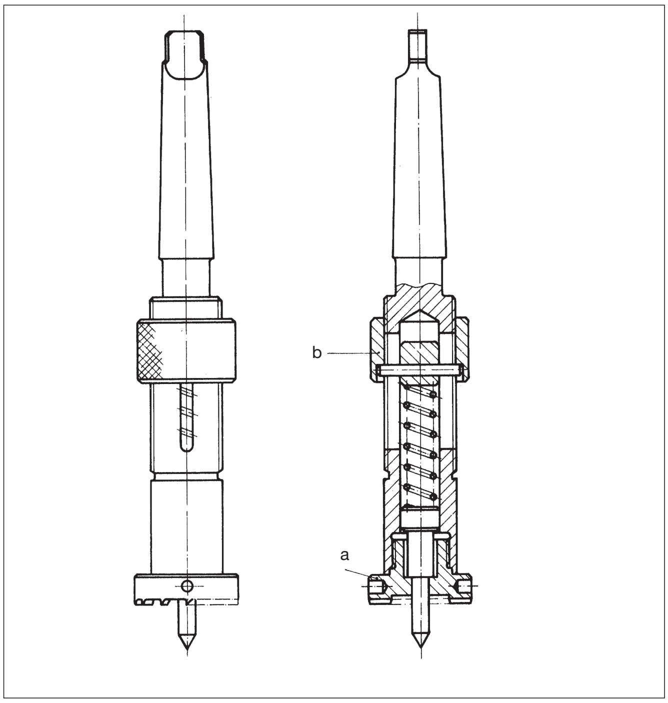


Fig. 10.02 **Pivot Welding on Drilling Machines**

The pressure of the point can be adjusted, by the knurled nut b, to suit the joint surface. The tightness and strength of the weld will depend on the pressure, and the correct pressure must be determined by experiment.

To make a weld, the drill spindle is lowered slowly until the tooth crown is still a few millimeters above the plastic part (Fig. 10.03a). Contact should then be made sharply, to prevent the teeth from shaving off the material, and so that the part starts rotating immediately. In the form shown in Fig. 10.03b, the pressure should be kept as constant as possible until a uniform flash appears. Then the tooth crown is pulled up as sharply as possible (Fig. 10.03c) until the teeth disengage, but with the point still pressed against the part until the plastic has hardened sufficiently.

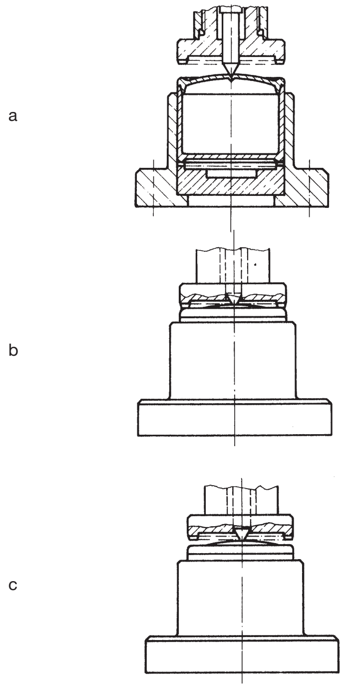


Fig. 10.03 **Drill spindle positions**

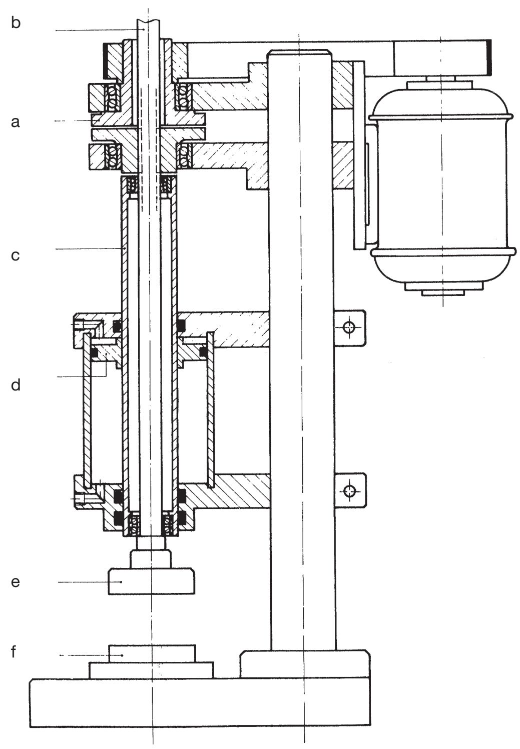


Fig. 10.04 **Pivot Welding on Special Machines**

The function of the point, therefore, is merely to apply the appropriate pressure. All the same, the plastic parts should be provided with a centering recess to guide the tool and to obtain uniform vibrationless rotation.

For a good weld a certain amount of heat is needed, which will depend on the plastic in question; it is a product of the pressure, the speed and the cycle time. At the same time, the product of pressure times speed must not be below a certain minimum value, or else the joint faces will only wear without reaching the melting point. The coefficient of friction is important too. Clearly all these factors vary from one plastic to another, and must be determined for each case. (For the shape and arrangement of the driving teeth, see Chapter 7).

As a first approximation, the peripheral welding speed for DELRIN® and ZYTEL® should be chosen between 3 and 5 m/s. Then the pressure must be adjusted until thedesired result is obtained in a welding time of 2 to 3 seconds.

For good results, a correct weld profile is of course essential. For suggestions and dimensions, see Chapter 8.

Pivot Welding on Specially Designed Machines

To make the method we have just described fully automatic involves a certain amount of machine investment, so that it is now very rarely used in large-scale production. But special machines, based on an adaptation of this method, have been built which are much easier to operate (Fig. 10.04).

The machine has an electromagnetic clutch *a*, which makes it very easy to engage and disengage the working spindle *b*, which rotates in a tube *c* which also carries the air-piston *d*. The head *e* can take either a tooth crown or one of the other jigs described in a later section, depending on the particular plastic component to be welded.

The welding procedure is as follows:

– Both parts are inserted into the bottom holder *f*.
– The piston (operated by compressed air) and its working spindle are lowered.
– The clutch engages, causing the top plastic part to rotate.
– After a certain period (controlled by a timer) the clutch disengages, but pressure continues to be applied for a further period (depending on the type of plastic).
– The spindle is raised and the welded article ejected (or the turntable switched to the next position).

In suitable cases, a tooth crown may be employed to grip the part (Fig. 10.16). Alternatively, projections on the part such as ribs, pins, etc., can be employed for driving, because the spindle is not engaged until after the part has been gripped.

Fig. 10.05 shows an example of a part with four ribs gripped by claws. Thin-walled parts need a bead *a* to ensure even pressure around the entire weld circumference. The claws do not, in fact, apply any pressure, but transmit the welding torque.

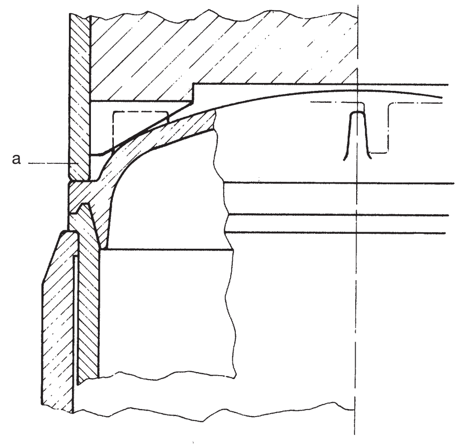


Fig. 10.05 **Drill spindle with claws**

It is sometimes not possible to use this method. For instance, the cap with a tube at the side, shown in Fig. 10.06, must be fitted by hand into the top jig before the spindle is lowered. This process cannot of course easily be made automatic.

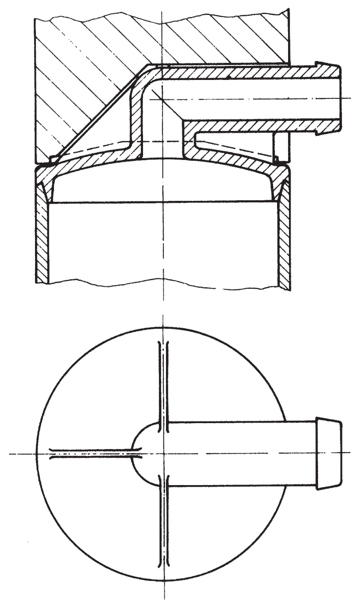


Fig. 10.06 **Special drill spindle**

Another possibility is for the spindle to be kept stationary, as shown in Fig. 10.07, and for the bottom jig to be placed on top of the compressed-air cylinder.

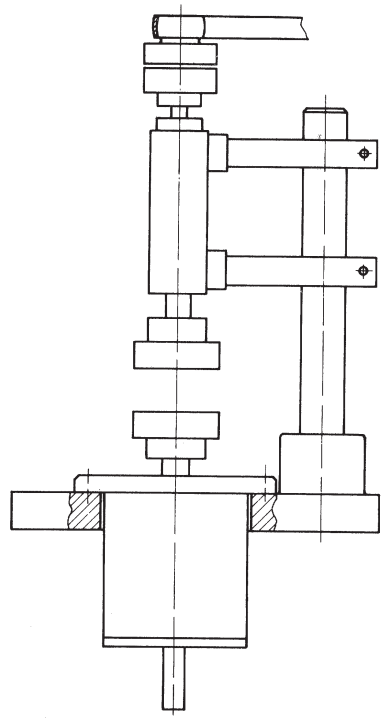


Fig. 10.07 **Pivot Welding with Stationary Spindle**

This simplifies the mechanical construction, but it is impossible to fit a turntable and thus automate the process.

One of the disadvantages of the methods described, compared to inertia machines, is that more powerful motors are required, especially for large diameters and joint areas.

Inertia Welding

By far the simplest method of spinwelding, and the most widespread, is the inertia method. This requires minimum mechanical and electrical equipment, whilst producing reliable and uniform welds.

The basic principle is that a rotating mass is brought up to the proper speed and then released. The spindle is then lowered to press the plastic parts together, and all the kinetic energy contained in the mass is converted into heat by friction at the weld face.

The simplest practical application of this method involves specially built tools which can be fitted into ordinary bench drills. Fig. 10.08 shows a typical arrangement. The mass *a* can rotate freely on the shaft *b*, which drives it only through the friction of the ball bearings and the grease packing.
As soon as the speed of the mass has reached that of the spindle, the latter is forced down and the tooth crown *c* grips the top plastic part *d* and makes it rotate too. The high specific pressure on the weld interfaces acts as a brake on the mass and quickly brings the temperature of the plastic up to melting point.

Once again, pressure must be kept on for a short period, depending on the particular type of plastic.

The tool illustrated in Fig. 10.08 has no mechanical coupling, so that a certain period of time (which depends on the moment of inertia and the speed of the spindle) mustelapse before the mass has attained the necessary speed for the next welding operation, and with larger tools or an automatic machine this would be too long. Moreover, there is a danger – especially when operating by hand – that the next welding cycle will be commenced before the mass has quite reached its proper speed, resulting in a poor quality weld. The tool shown in Fig. 10.08 should therefore only be used for parts below a certain size (60-80 mm in diameter).

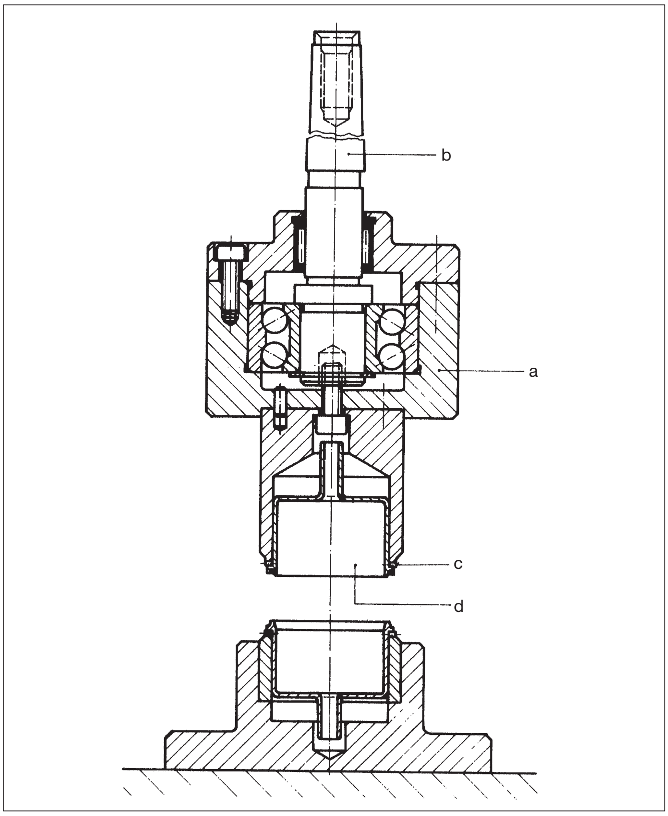


Fig. 10.08 **Inertia Welding using ordinary bench drills**

Since small components can also be welded with fly-wheels if high speeds are used, very small tools (30-50 mm in diameter) are sometimes constructed which will fit straight into the drill chuck. Fig. 10.09 shows such an arrangement, for welding plugs. Since speeds as high as 8000 to 10 000 rpm are needed, a pivot tool like that in Fig. 10.02 is sometimes preferred.

For tools with diameters over 60-80 mm, or where a rapid welding cycle is required, a mechanical coupling like in Fig. 10.10 is best. Here the mass *a* can move up and down the shaft *b*. When idling, the springs *c* force the mass down so that it engages with the shaft via the cone coupling *d*. The mass then takes only an instant to get up to its working speed.

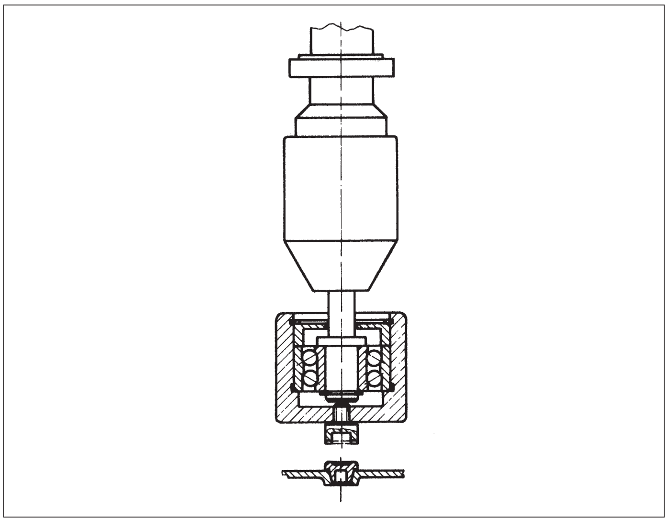


Fig. 10.09 **Inertia Welding for small components**

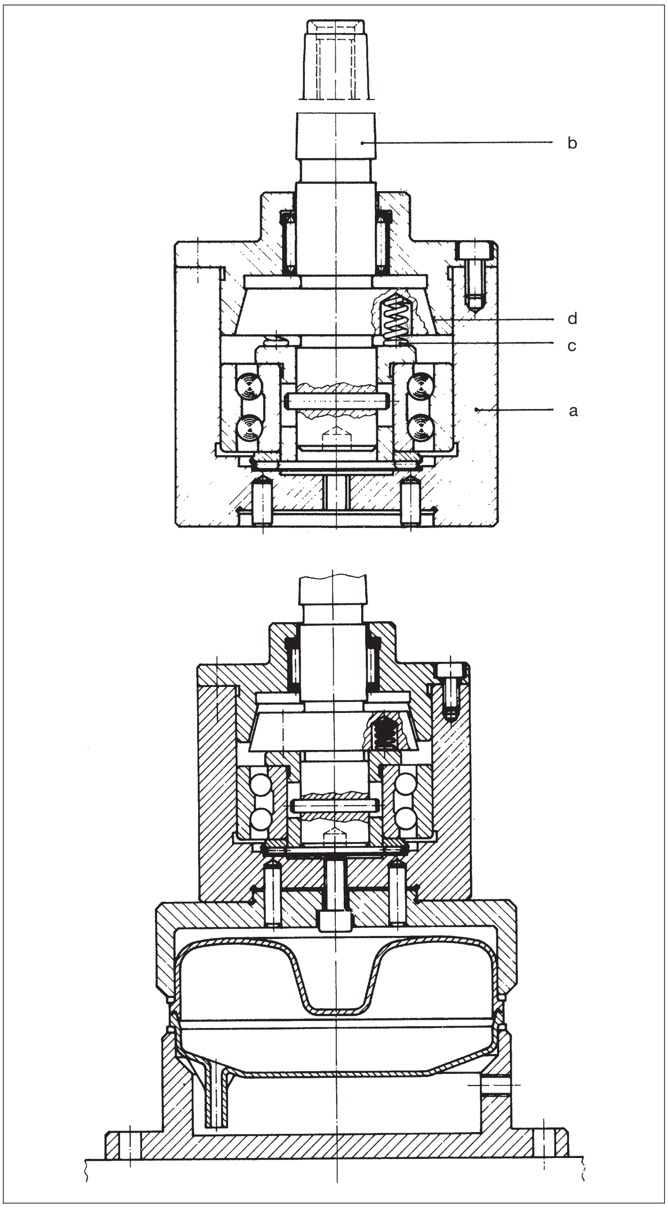


Fig. 10.10 **Inertia Welding, Mechanical Coupling**

As soon as the spindle is lowered and the tooth crown grips the plastic, the mass moves upwards and disengages (Fig. 10.10a). But since the pressure of the spindle is not fully transmitted until the coupling reaches the end of its stroke, there will be a delay in gripping the part, with the result that the teeth tend to shave off the plastic, especially when the spindle does not descend fast enough.

A lined flat clutch (as shown in Fig. 10.13) can of course be used instead of a hardened ground cone clutch.

The following rules must be observed when using inertia tools in drilling machines:

1) The spindle must be lowered sharply. The usual commercial pneumatic-hydraulic units fitted to drilling machines are too slow.
2) The pressure must be high enough to bring the tool to rest after 1-2 revolutions. This is particularly important with crystalline plastics with a very sharply defined melting point. (See general welding conditions.)
3) Inertia tools must be perfectly round and rotate completely without vibration. If they have a Morse cone, this must be secured against loosening. It is best to use a Morse cone having an internal screw thread within anchoring bolt (hollow spindle). *Fatal accidents can result from the flywheel coming loose or the shaft breaking.*
4) The downwards movement of the spindle must be limited by a mechanical stop, so that the two jigs can never come into contact when they are not carrying plastic parts.

Although uniformly strong welds can be made when operating these drilling machines by hand, the use of compressed air is firmly recommended even for short production runs. Such a conversion is most easily done by adding a rack and pinion as shown in Fig. 10.11.

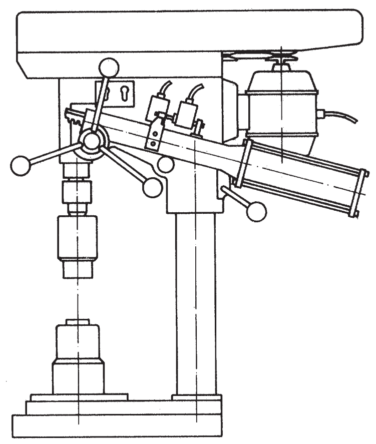


Fig. 10.11 **Inertia Welding, Rack and Pinion Conversion**

Moreover, it is advisable to have a machine with variable-speed control, so as to be able to get good results with no need to modify the mass. It is only worthwhile converting a drilling machine if this is already available; if starting from scratch, it is better to buy a machine specially designed for spinwelding.

Machines for Inertia Welding

The principle of the inertia welding machine is so simple that it is possible to build one with very little investment.

If the machine is mainly used for joining one particular pair of components, it will not generally require to have facilities for varying the speed. If this should prove necessary, it can be done by changing the belt pulley.

Except for the welding head, the machine shown in Fig. 10.12 is entirely built from commercially available parts. It consists basically of the compressed air cylinder *a*, which supports the piston rod at both ends and also the control valve *b*. The bottom end of the piston rod carries the welding head *c* (see Fig. 10.13), driven by the motor *d* via the flat belt *e*. The machine also incorporates a compressed air unit *f* with reducing valve, filter and lubricating equipment.

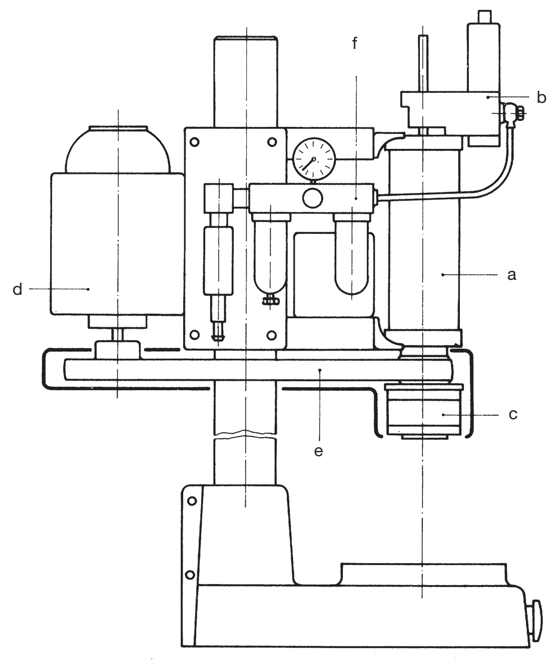


Fig. 10.12 **Inertia Welding Machine**

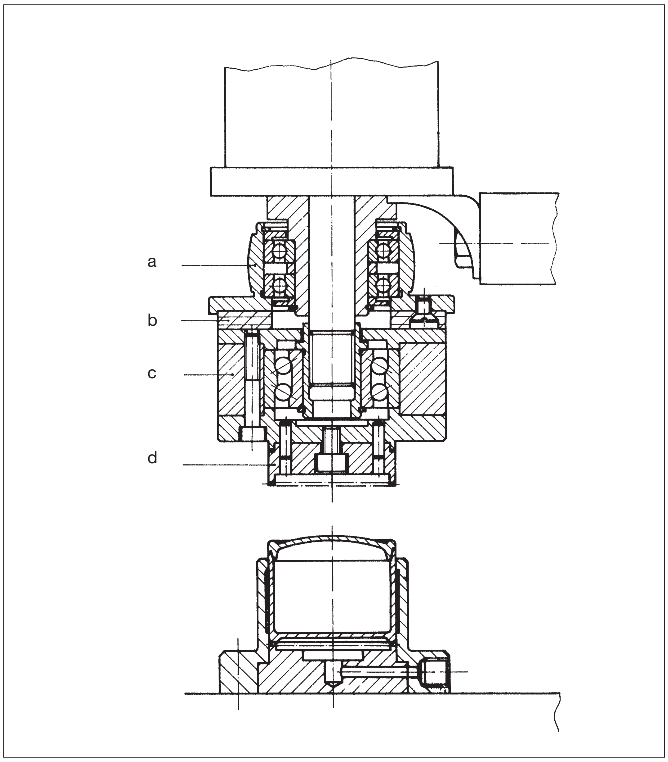


Fig. 10.13 **Inertia Welding Machine Head**

The welding head shown in Fig. 10.13 (designed by DuPont) consists of a continuously rotating belt pulley *a*, which carries the coupling lining *b*. In the drawing, the piston rod is at the top of its stroke and the movement of rotation is transmitted via the coupling to the flywheel *c*.

As the spindle descends, the coupling disengages and the tooth crown grips the top of the float, shown as an example.

If it is impossible to grip the part with a tooth crown, and it has to be fitted into the top jig by hand (as in Fig. 10.06, for example), an extra control will be necessary. The piston will have to pause on the upstroke just before the coupling engages, to enable the parts to be inserted. This can be managed in various ways. For example, one can buy compressed air cylinders fitted with such a device. A pulse passes from the travelling piston directly to a Reed switch on the outside.

So that the parts may be taken out conveniently, the piston stroke must generally be about 1,2 times the length of the entire finished welded part. Long parts require considerable piston strokes, which is impractical and expensive. Fig. 10.14 shows a typical example – a fire-extinguisher – for which a piston stroke 1,2 times the length of the part would normally have been needed.

However, there are various ways of circumventing this:

1) The bottom holder *a*, can be fitted with a device for clamping and centering, so that it can easily be released by hand and taken out sideways.
2) Two holders are fitted, *a* and *b*, which can swivel through 180° about the axis X-X by means of a turntable *c*. The completed article is removed and changed while the next one is being welded; this reduces the total welding cycle.
3) If the production run justifies it, a turntable can of course be used; it may, for instance, have three positions: welding, removal and insertion.

The above steps allow the piston stroke to be shortened considerably, thus avoiding the potentially lethal arrangement of having the rotating mass on a piston rod which projects too far.

Since the welding pressure is fairly high, the clutch lining and the ball-bearings of the pulley will be under an unnecessarily heavy load when in the top position. It is therefore advisable to operate at two different pressures, although this does involve a more complicated pneumatic control. Alternatively, a spiral spring can be incorporated above the piston, to take up some of the pressure at the top of its stroke.

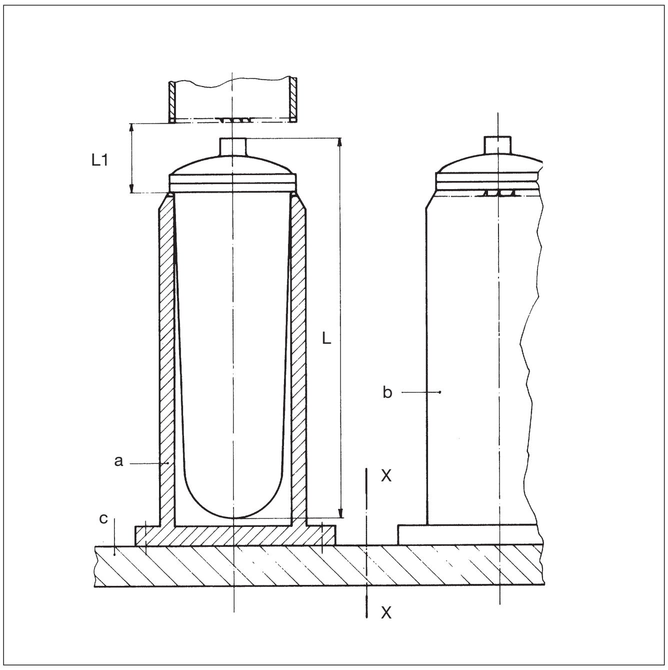


Fig. 10.14 **Inertia Welding, long parts**

In any case, the speed of the piston must be reduced sharply just before contact is made, so as to reduce the initial acceleration of the flywheel and protect the clutch lining.

On machines equipped with a turntable the parts are ejected after being removed from under the spindle. In such cases, the piston stroke can be much shorter, as, for example, with the float shown in Fig. 10.13.

It is also possible to produce the pressure by means of the diaphragm device shown in Fig. 10.15. The rubber diaphragm is under pressure from compressed air above it and from a spring below. The spring must be strong enough to raise the flywheel and to apply sufficient force to engage the clutch. In a production unit it is best to guide the shaft by means of axial ball-bearings. The advantages of this device over an ordinary cylinder are lower friction losses and a longer life. However, the permissible specific pressures on the diaphragm are limited, so that larger diameters are needed to achieve predetermined welding pressures. (The welding head, with flywheel and belt pulley, is identical with that shown in Fig. 10.13).

The rubber diaphragm mechanism is suitable for a piston strocke up to 10-15 mm and for specific pressures of 3 to 4 bar.

Since, as has already been mentioned, the operating speed can be altered by changing the motor belt pulley, a variable speed motor is not essential. In any production run there will be cases in which some possibility of limited speed adjustment would seem to be desirable.

The kinetic energy of the flywheel is a function of the square of the speed (rpm), so it is important to keep the speed as constant as possible.

This is not always easy, because appreciable motor power is only needed during acceleration of the mass. Once the operational speed has been reached, only the friction needs to be overcome, for which a very low power is sufficient. The motor is now practically idling, and may get into an unstable state (e.g., with series-connected collector motors).

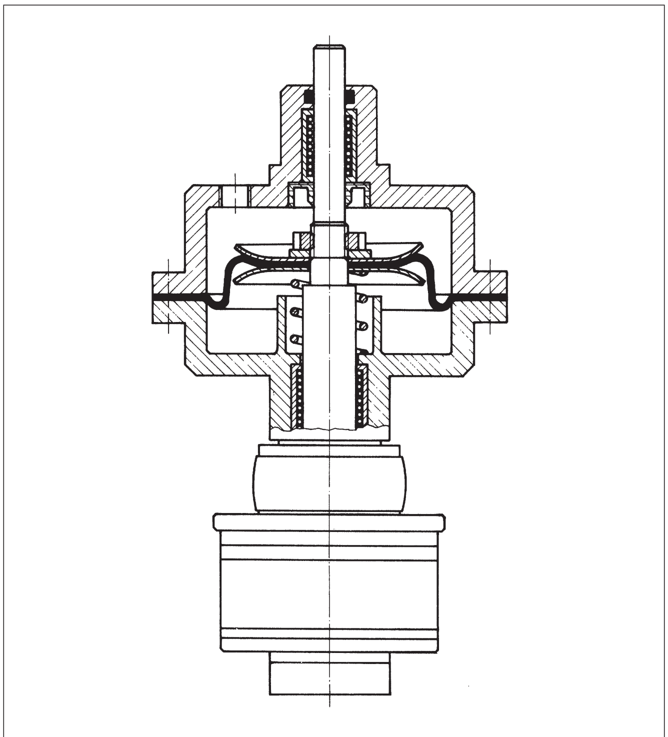


Fig. 10.15 **Welding Head with Diaphragm**

Examples of suitable drives for this type of rotation-welding machines are:

- Repulsion motors, based on the principle of adjustable brushes. Single-phase 0,5 kW motors operating at about 4000 rpm are generally adequate. A disadvantage of this kind of motor is the difficulty of fine speed control.
- Thyristor controlled three-phase or single-phase squirrel cage motors. The control unit must enable speed to be adjusted independently for the load, which is not always the case.
- D.C. shunt motors with armature voltage adjustment. These are very suitable. Control unit costs are very modest, so that the overall cost remains reasonable. The speed can be kept constant enough without using a tacho-generator and the control range is more than sufficient.

Experimental welding machines, or production machines used for parts of different diameters, must be fitted with one of these types of motor.

For machines used only for joining one particular component, a variable-speed drive is not absolutely essential, although of course very useful. If the machine has a fixed-speed drive, then it is better to start operating at a rather higher speed than is strictly necessary. This builds up a little extra energy, so that proper welds will still be made even when the joints fit together badly because of excessive moulding tolerances. Of course, more material will be melted than is strictly necessary.

Compressed air motors or turbines are occasionally used to drive the machines, but they are more expensive, both in initial investment and in running costs, than electric motors, and do not present any advantage.

Jigs (Holding Devices)

These can be subdivided depending on whether:

- the parts are gripped by a jig which is already rotating as the spindle descends; or
- the parts must be placed in the jig when the spindle is stationary.

In the first case, the cycle time is shorter, and this solution is therefore preferred whenever possible. The following types of jigs are suitable:

- A tooth crown as in Fig. 10.16 will grip the plastic part, as the spindle descends, and cause it to rotate with it. If the teeth are designed properly, and the piston moves fast enough, the unavoidable toothmarks made in the plastic can be kept small and clean. The cutting edges of the teeth must be really sharp. The teeth are not generally ground, but the crown must be hardened, especially on production machines.

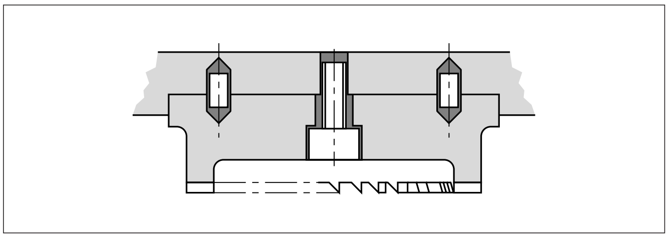


Fig. 10.16 **Jig Tooth Crown**

– The dimensions indicated in Fig. 10.17 are intended to be approximate; dimensions should be matched to the diameter of the part. With very thin-walled parts, it is better to reduce the distance between the teeth toensure that enough pressure is exerted on the joint.

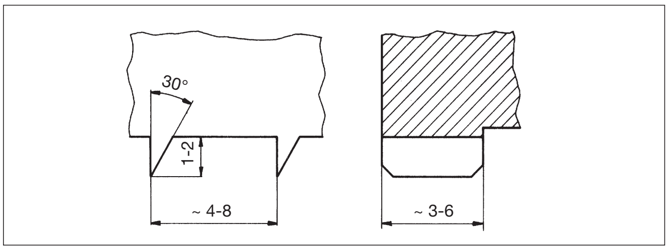


Fig. 10.17 **Suggested Tooth Dimensions**

– With larger or more complicated jigs it is better to design the tooth crown as a separate part which can be changed if necessary.

– Fig. 10.18 shows two typical weld sections with their corresponding tooth crowns and jigs.

– If the joints have no protruding bead, the bottom holder *a*, must fit closely, so as to prevent the part from expanding (especially if the wall is thin). The top of the plastic part, *b*, should if possible have a rounded bead, to make it easier for the teeth *c* to grip.
  With inertia-type machines, an outer ring *d* is often necessary to centre the part accurately, especially if there is too much play between the bottom plastic part and its holder, or if the piston-rod guides are worn.

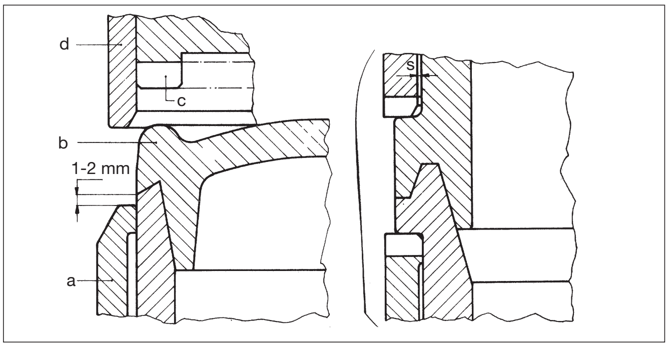


Fig. 10.18 **Typical Weld Sections**

– The bottom half of the plastic part can be fitted with an identical tooth crown (see also Figs. 10.13 and 10.20) to prevent its rotating. With the Venturi tube shown in Fig. 10.19, its side part is used for retention. Obviously this makes automatic insertion very difficult, if not impossible. The lower part is about 200 mm long, which in itself would make automation too complicated. This is a good example of what was said before about the minimum lenght of piston stroke. Since the total length of the welded parts is about 300 mm, the piston stroke would have to be about 350 mm; a machine like this would be impractical and expensive; and the rotating flywheel on the long piston-rod would be very dangerous. This problem could be avoided by using a turntable, but this would not be very practical either, because the parts are so long.

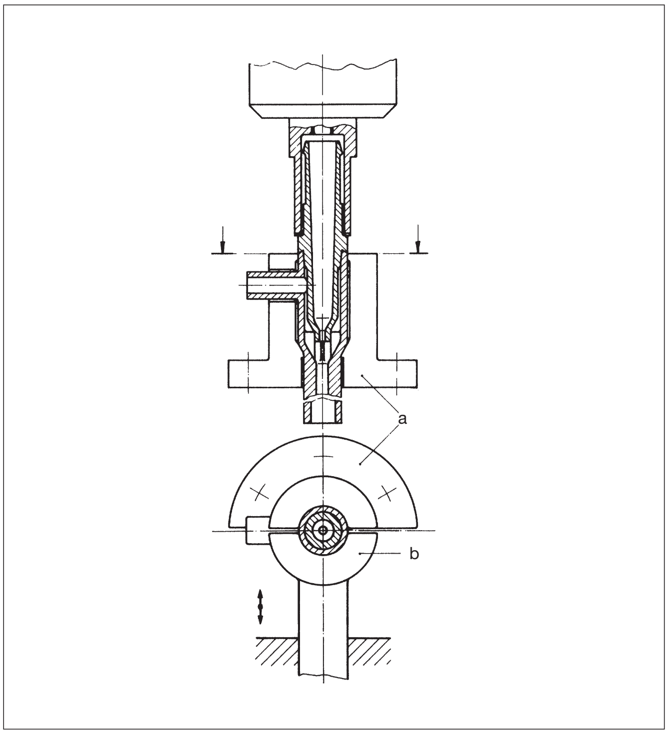


Fig. 10.19 **Part with Venturi tube**

– The arrangement suggested in the drawing shows a holder *a*, which embraces one half of the part only, the other being held by a pneumatic device *b*. This enables the piston-stroke to be kept short, and the parts are easily inserted and removed. In addition, the joints are supported around their entire circumference.

– Frequently the tooth crown cannot be sited immediately above the weld; e.g., with the float shown in Fig. 10.20 this is impossible for technical reasons. In such cases the length *L*, i.e. the distance between weld and tooth crown, must be in proportion to the wall thickness, so that the high torque and the welding pressure can be taken up without any appreciable deformation. This will of course also apply to the bottom plastic part.

– Selection of the joint profile and of the jig is often governed by the wall thickness.

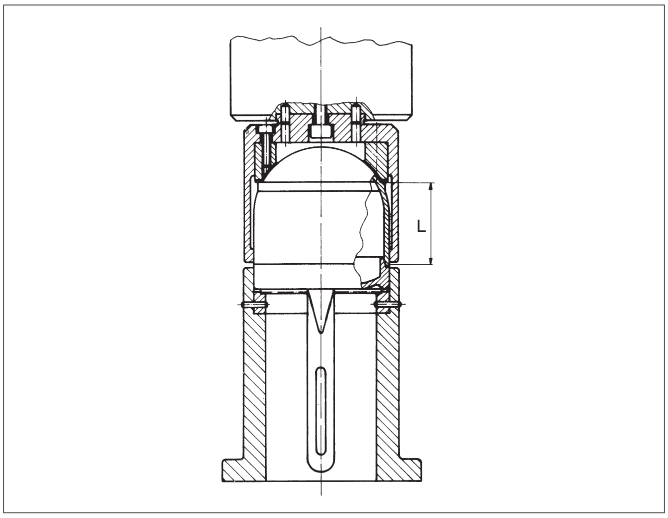


Fig. 10.20 **Part with Venturi tube**

Couplings with Interlocking Teeth

Instead of a tooth crown which has to be pressed into the plastic in order to transmit the torque, toothed couplings are occasionally used, and matching teeth are moulded into the plastic part; they may either protrude or be recessed (as in Fig. 10.21), whichever is more convenient.

The holder *a*, will have equal and opposing teeth, and when the plastic part is gripped no damage is caused. Ring faces *b* inside and outside the coupling will transmit the welding pressure to the part, so that the teeth, in fact, transmit only the torque. The number of teeth should be kept small to reduce the danger of their tips breaking off.

These tips should not be too sharp; the teeth should terminate in a tiny face *c* 0,3-0,5 mm.

This solution is also suitable for the pivot tools described before, which do not rotate as fast as inertia machines. With the high peripheral speed of inertia machines, it is more difficult to ensure that the teeth engage cleanly.

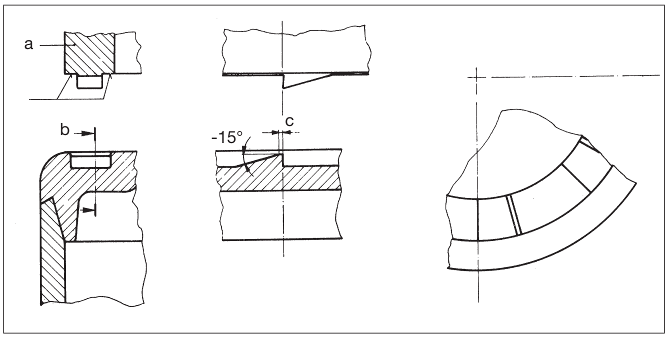


Fig. 10.21 **Couplings with interlocking teeth**

Cast Resin Couplings

In certain cases it is also possible to drive or grip the parts by means of elastomer jigs. Synthetic resins are cast directly into the holding device, the plastic parts forming the other portion of the mould, so as to get the right-shaped surface.

Since the maximum torque which can be transmitted in this manner is low, and the permissible pressure per unit area is low too, this method is only worth considering for parts having relatively large surfaces.

Conical parts are the most suited to this type of jig (see Fig. 10.22), because a greater torque can be transmitted for a given welding pressure.

When this type of jig is used with an inertia machine and the plastic part has to be accelerated to its welding speed, there is bound to be a certain amount of slip; this can cause excessive heating of the surface.

It is therefore extremely important to select a casting resin of the right hardness; this has to be determined experimentally. Fig. 10.22 shows, in essence, how the cast elastomer *a*, also has to be anchored to the metal parts by bolts, undercuts or slots. The recesses *b* are machined out afterwards, because contact here should be avoided.

Making cast resin grips requires a lot of experience and suitable equipment. The initial costs of this method are therefore considerable and it has not found many practical applications.

It may however be economically worth considering for machines with turntables which need several holders.

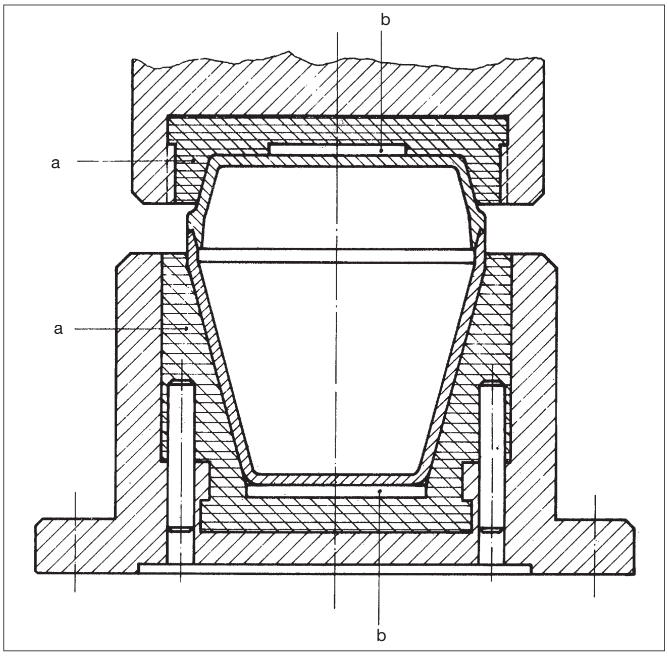


Fig. 10.22 **Cast Resin Coupling**

Joint Profiles

If welded joints are to be tight and strong, some attention must be paid to the joint profiles. The strength of the weld should be at least as great as that of its two component parts, so that the area of the weld face must be about 2-2,5 times the cross-section of the wall.

V-profiles, used for many years now, have proved far the best; Fig. 10.23 shows two typical examples.

The joint profile in Fig. 10.23a is suitable for parts having equal internal diameters, which can be provided with external shoulders for the purpose of driving or gripping. (For example, cylindrical containers or pressure vessels which have to be made in two parts on account of their length).

The profile in Fig. 10.23b is particularly suitable for the welding-on of bases or caps (for instance, on butane gas lighter cartridges, fire extinguishers, or aerosol bottles).

The wall thickness dimensions given are only suggestions; the structure of the parts must of course also be taken into consideration. But the area of the joint face should never be reduced. Plastics which have a high coefficient of friction tend to be self-locking if the angle of inclination is too small, preventing the tooth crown from rotating and causing it to mill off material. Angles of less than 15° should therefore be employed only with the greatest care.

For profiles like that in Fig. 10.23a, a certain amount of play should be provided for, before welding, between the surfaces at right angles to the axis of the part. This ensures that the entire pressure is first exerted on the inclined faces, which account almost entirely for the strength of the joint.

It is impossible to prevent softened melt from oozing out of these joints and forming flash, which is often a nuisance and has to be removed afterwards. If the welded vessels contain moving mechanical parts, loose crumbs of melt inside could endanger their correct functioning and cannot therefore be allowed.

Figs. 10.24a-d show four suggested joint profiles, all of which have grooves to take up the flash.

The simple groove flash trap shown in Fig. 10.24a will not cover up the melt but will prevent it from protruding outside the external diameter of the part; this is often sufficient. The overlapping lip with small gap, shown in Fig. 10.24b, is common.

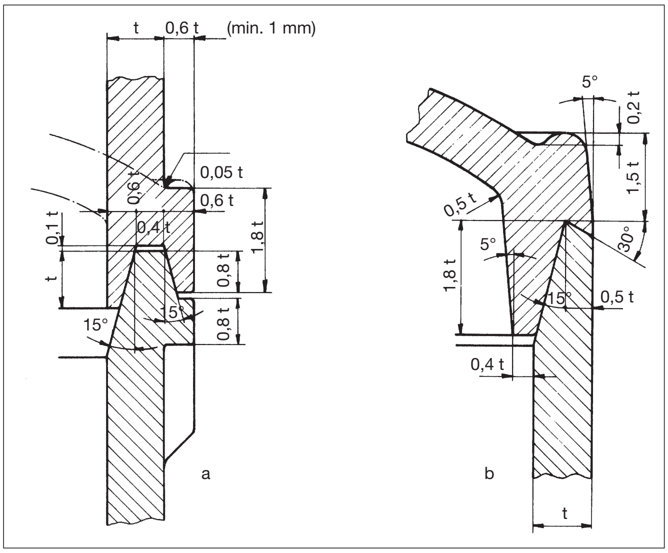


Fig. 10.23 **Joint Profiles**

Fig. 10.24c shows flash traps so arranged that they are closed when welding is complete. Fig. 10.24d shows a lip with a slight overlap on the inside, which seals the groove completely and prevents any melt from oozing out. The external lip will meet the opposite edge when the weld is complete.

The type of weld profile shown in Fig. 10.23b can also be given an edge which projects to the same extent as the top of the container.

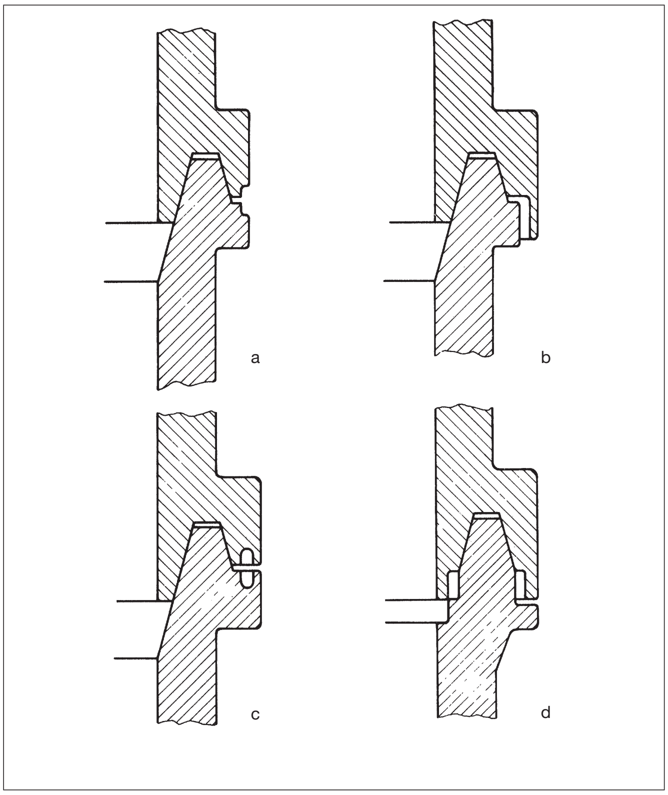


Fig. 10.24 **Joint Profiles with flash traps**

Fig. 10.25 shows such a design, used occasionally for butane refill cartridges. Generally an open groove is good enough. A thin undercut lip *a*, can also be used, so that the flash trap becomes entirely closed. Of course, a lip like this can be provided on the outside too, but it demands more complicated tooling for the ejector mechanism and should not therefore be used unless absolutely essential.

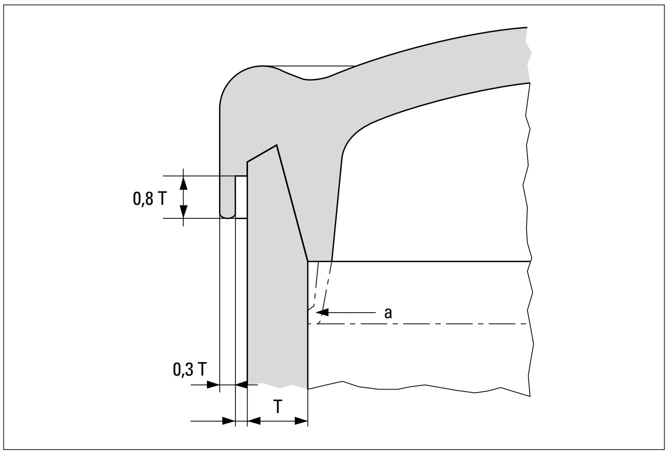


Fig. 10.25 **Joint with prevented outside protrusion**

Calculations for Inertia Welding Tools and Machines

In order to bring a plastic from a solid to a molten state a certain amount of heat, which depends on the type of material, is necessary. Engineering plastics actually differ very little in this respect, and so this factor will be neglected in the following discussion.

The quantity of heat required for melting is produced by the energy of the rotating masses. When the joint faces are pressed together, the friction brings the flywheel to a stop in less than a second.

With plastics having a narrow melting temperature range, such as acetal resins, the tool should not perform more than one or two revolutions once contact has been made. If the pressure between the two parts is too low, the flyweight will spin too long, and material will be sheared off as the plastic solidifies, producing welds which are weak or which will leak.

This factor is not so important with amorphous plastics, which solidify more slowly. For all plastics, it is best to use higher pressures than are absolutely necessary, since in any case this will not cause the weld quality to suffer.

To get good results with inertia machines, the following parameters should be observed:

a) *Peripheral speed at the joint*

As far as possible, this should not be lower than 10 m/s. But with small diameter parts it is occasionally necessary to work between 5 and 10 m/s, or else the required rpm's will be too high. In general, the higher the peripheral speed, the better the result. High rpm's are also advantageous for the flywheel, since the higher the speed, the smaller the mass needed for a given size of part to be joined.

b) *The flywheel*

Since the energy of the flywheel is a function of its speed of rotation and of its moment of inertia, one of these parameters must be determined as a function of the other. The kinetic energy is a function of the square of the speed (rpm's), so that very slight changes in speed permit adjustment to the required result.
In general, for engineering plastics, the amount of effort needed to weld 1 cm^2 of the projection of the joint area is about 50 Nm.
The amount of material which has to be melted also depends on the accuracy with which the two profiles fit together, and therefore on the injection moulding tolerances. It would be superfluous to carry out too accurate calculations because adjustments of the speed are generally required anyway.

c) *Welding pressure*

As mentioned above, the pressure must be sufficient to bring the mass to rest within one or two revolutions. As a basis for calculation, we may assume that a specific pressure of 5 MPa projected joint area is required. It is not enough merely to calculate the corresponding piston diameter and air pressure; the inlet pipes and valves must also be so dimensioned that the piston descends at a high speed, as otherwise pressure on the cylinder builds up too slowly. Very many of the unsatisfactory results obtained in practice stem from this cause.

d) *Holding pressure*

Once the material has melted, it will take some time to re-solidify, so that it is vital to keep up the pressure for a certain period, which will depend on the particular plastic, and is best determined experimentally.
For DELRIN®, this is about 0,5-1 seconds, but for amorphous plastics it is longer.

Graphical Determination of Welding Parameters

The most important data can be determined quickly and easily from the nomogram (Fig. 10.26) which is suitable for all DuPont engineering plastics.

Example: First determine the mean weld diameter *d* (Fig. 10.27) and the area of the projection of the joint surface *F*.

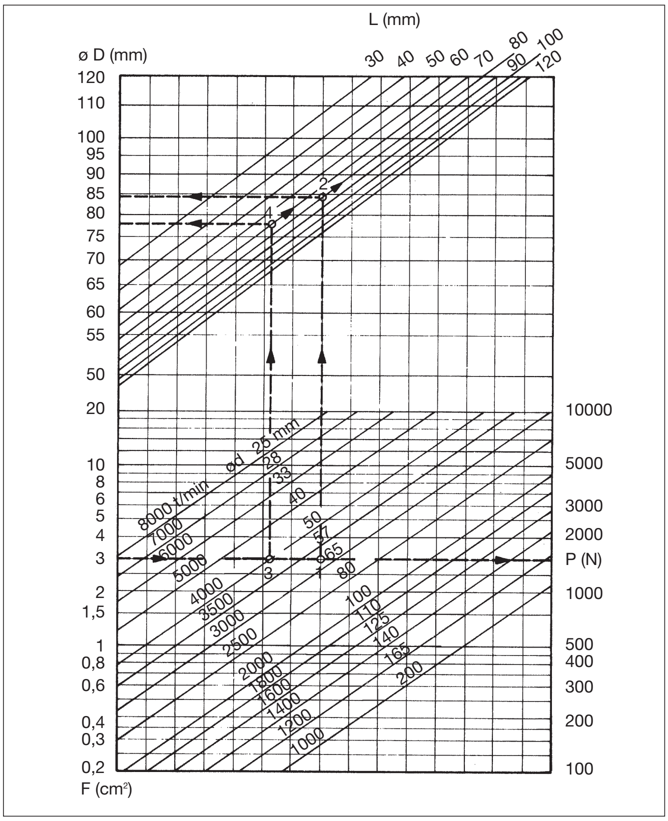


Fig. 10.26 **Determination of Welding Parameters**

For the example illustrated, *F* is about 3 cm^2 and the mean weld diameter *d* = 60 mm. Starting at 3 cm^2 on the left-hand scale, therefore we proceed towards the right to meet the line which corresponds to a diameter of 60 (Point 1), and then proceed vertically upwards. A convenient diameter and associated length of flywheel (see Fig. 10.28) are chosen. But the diameter should always be greater than the length, so as to keep the total length of the rotating flywheel as small as possible. In the example illustrated, a diameter of approximately 84 mm has been chosen, giving a length of 80 mm (Point 2).

The nomogram is based on a peripheral speed of 10 m/s, which gives about 3200 rpm in this example (60 mm diameter). A higher speed can be chosen, say 4000 rpm, which corresponds to Point 3. The tool dimensions obtained by moving upwards from this point will of course be smaller than before.

In this example we have Point 4, which corresponds to a diameter of 78 mm and a length of 70 mm.

Moving towards the right from the point corresponding to 3 cm^2, the corresponding welding force required is read off from the right-hand scale; in this case, about 1500 N.

This nomogram considers only the external dimensions of the tools, and ignores the fact that they are not solid; but the jig to some extent compensates for this, and the values given by the nomogram are accurate enough.

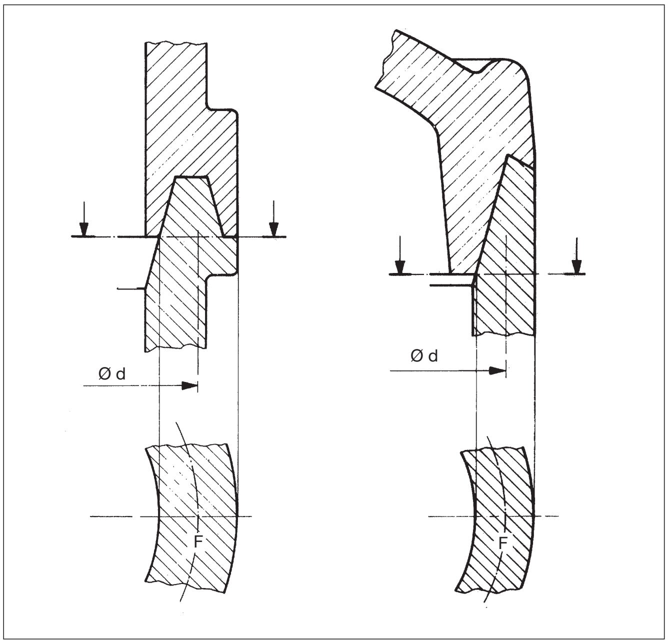


Fig. 10.27 **Welding Parameters Example**

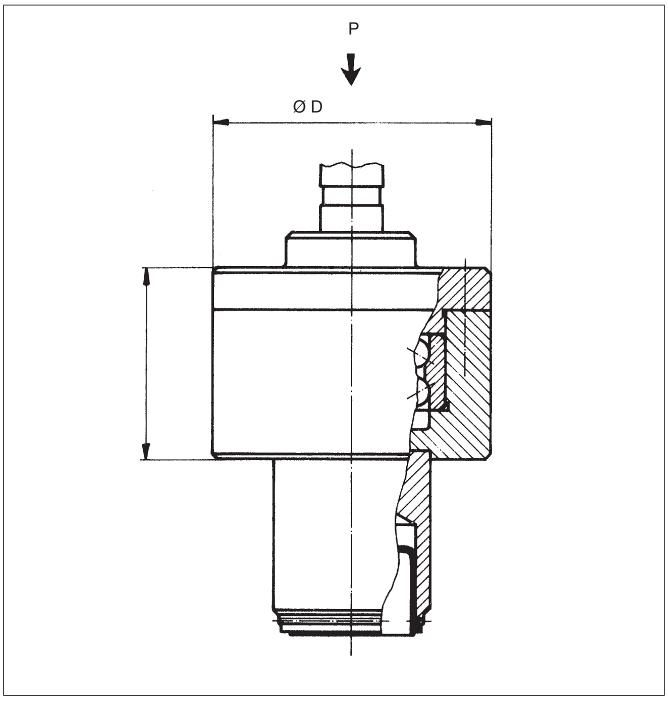


Fig. 10.28 **Flywheel Size Example**

Motor Power

In addition to their many other advantages, inertia tools require only a very low driving power.

In a fully or semi-automatic machine, the entire cycle lasts between 1 and 2 seconds, so that the motor has sufficient time to accelerate the flyweight up to its operating speed. During welding the kinetic energy of the tool is so quickly converted into heat that considerable power is generated.

For example, if the two tools considered in the nomogram of Fig. 10.26 are stopped in 0,05 s, they will produce about 3 kW during this time. If a period of 1 second is available for accelerating again for the next welding cycle, a rating of only 150 W would theoretically be required.

0,5 kW motors are sufficient to weld most of the parts encountered in practice.

We have already mentioned that it is highly desirable to be able to vary the speed. With production machinery which always welds identical parts, the speed can be adjusted by changing the belt pulleys.

Quality Control of Welded Parts

To ensure uniform quality, the joint profiles should first be checked on a profile projector to see that they fit accurately. Bad misfits and excessive variations in diameter (due to moulding tolerances) cause difficulties in welding and poor quality welds. Correctly dimensioned joint profiles and carefully moulded parts will render systematic checking at a later stage superfluous.

If, for example, the angles of the two profiles do not match (Fig. 10.29), the result will be a very sharp notch which can lead to stress concentrations under heavy loads, thus reducing the strength of the entire part. It also means that too much material has to be melted away.

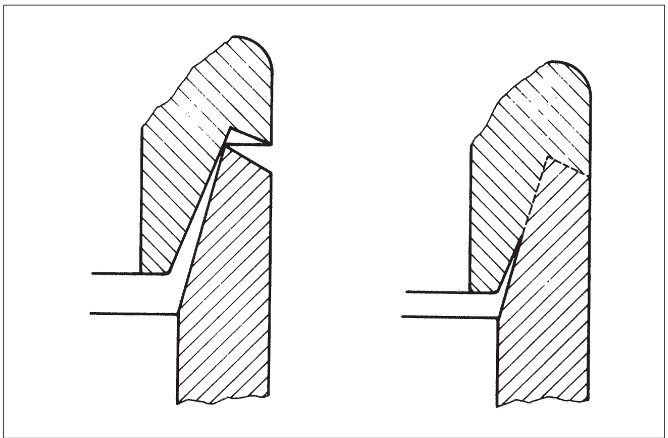


Fig. 10.29 **Joint with bad angles**

The essential criteria for weld quality are the mechanical strength and water-tightness or air-tightness, or both. The following methods are available for testing:

a) *Visual inspection* of welds has a very limited application and gives no information about strength or tightness. It can only be carried out when the flash is actually visible, i.e. not contained in a flash trap. When welding conditions are correct, a small quantity of flash should form all round the weld. If it is irregular or excessive, or even absent altogether, the speed should be adjusted. Naturally, only as much plastic should be melted as is absolutely necessary. But if no flash is visible at all, there is no guarantee that the joint has been properly welded (always assuming, of course, that there is no flash trap).

   The appearance of the flash depends not only on the type of plastic but also on its viscosity and on any fillers. For example, DELRIN® 100 produces rather a fibrous melt, while DELRIN® 500 gives a molten weld flash. The peripheral speed also affects the appearance, so it is not possible to draw any conclusions about the quality of the joint.

b) *Testing the strength* of the welds to destruction is the only way to evaluate the weld quality properly and to be able to draw valid conclusions.

   Most of the articles joined by spin welding are closed containers which will be under short-term or long-term pressure from the inside (lighters, gas cartridges, fire extinguishers) or from the outside (deep-water buoys). There are also, for example, carburettor floats, which are not under stress, and for which the joint only needs to be tight. For all these parts, regardless of the actual stresses occurring in practice, it is best as well as easiest to increase the internal pressure slowly and continuously until they burst. A device of this kind, described later on, should enable the parts to be observed while the pressure is increasing, and the deformations which take place before bursting very often afford valuable information about any design faults resulting in weak points.

   After the burst test, the entire part (but particularly the welded joint) should be examined thoroughly. If the weld profiles have been correctly dimensioned and the joint properly made, the weld faces should not be visible anywhere. Fracture should occur right across the weld, or along it. In the latter case, it is not possible to conclude whether or not the weld has been the direct cause of the fracture. This may have been the case when there is a severe notch effect as, for example, in Fig. 10.29.

   For parts which are permanently under internal pressure during service, and are also exposed to temperature fluctuations, the burst pressure must be eight to ten times the working pressure. This is the only guarantee that the part will behave according to expectation during the whole of its service life (butane gas lighters, for instance).

Since we are dealing only with cylinders, it is very helpful to determine the hoop stresses and compare them with the actual tensile strength of the plastic. If the ratio is poor, the cause of failure does not necessarily lie in the weld. Other causes may be: structural defects, orientation in thin walls unsatisfactory arrangement or dimensioning of the gates, weld lines, or bending of the centre core causing uneven wall thickness.

Glass fibre reinforced plastics are rather different. Higher glass content means higher strength, but the proportion of surface available for welding is reduced by the presence of the glass fibres. Consequently the ratio of the actual to the calculated burst pressure is low, and in certain cases the weld may be the weakest spot of the whole part.

The importance of correct design of pressure vessels for spin welding is shown by the following examples. After welding, the two cartridges in DELRIN® 500 acetal resin (Fig. 10.30) were tested to burst under internal pressure, and yielded the following results:

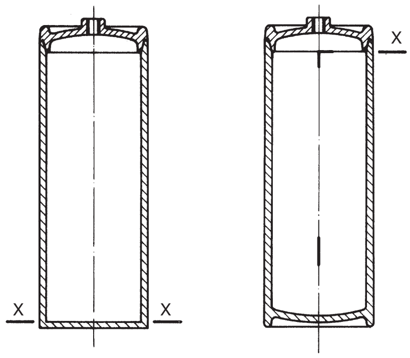


Fig. 10.30 **Designs of pressure cartridges**

Cartridge *A* split in the *X–X* plane, with no damage either to the cylinder or to the weld. This fracture is undoubtedly attributable to the flat bottom and sharp internal corner, i.e. to poor design. The burst pressure was only 37% of its theoretical value.

Cartridge *B* first burst in the direction of flow of the material, and then along the weld, without splitting it open. The burst pressure was 80% of the theoretical value, which can be considered acceptable.

However, it is not possible to draw any conclusions about water or gas tightness from the mechanical strength of the joint.

Pressure vessels and floats must therefore also be tested in the appropriate medium. Containers which will be under internal pressure are stressed to about half the burst pressure, which should enable all weak points to be detected. Floats and other tight containers are inspected by dipping into hot water and looking for bubbles at the joint.

It is, however, quicker and more reliable to test them under vacuum and a simple apparatus like that sometimes used for testing waterproof watches will often be all that is necessary.

– Fig. 10.31 illustrates the basic principle.
  A cylindrical glass vessel *a*, big enough to hold the part, is covered with a loose-fitting lid *b* and sealed with a rubber ring. The test piece is kept under water by the sieve *c*. Since the water level is almost up to the top of the vessel, only a small volume of air need be pumped out to produce an adequate vacuum; in fact, only a single stroke of a small hand pump will do. The rig should preferably be fitted with an adjusting valve to limit the degree of vacuum and prevent the formation of bubbles by boiling.

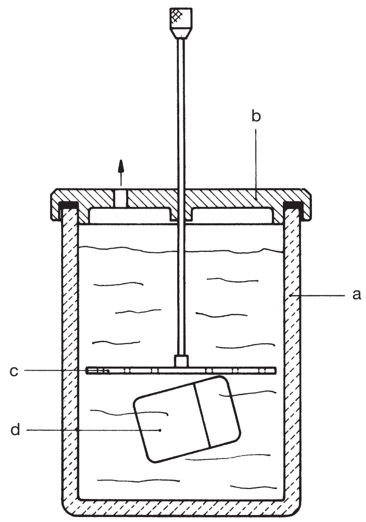


Fig. 10.31 **Tightness Test using Vacuum**

Checking Weld Joints by Inspection of Microtome Sections

Correct design and proper welding should render microtome sections superfluous. The making of these sections requires not only expensive equipment but also a considerable amount of experience.

However, such sections can occasionally result in the discovery of the causes of poor welds as, for example, in Fig. 10.32, which clearly shows how the V-groove was forced open by the welding pressure and the matching profile was not welded right down to the bottom of the V. The resulting sharp-edged cavity not only acted as a notch, but increased the risk of leaking.

Testing of spin welded joints should only be carried out at the beginning of a production run, and thereafter on random samples, except when there is a risk that some parameter in the injection moulding or the welding process may have changed. The percentage of rejects should remain negligible if the correct procedure is followed, and systematic testing of all welded components will not be necessary.

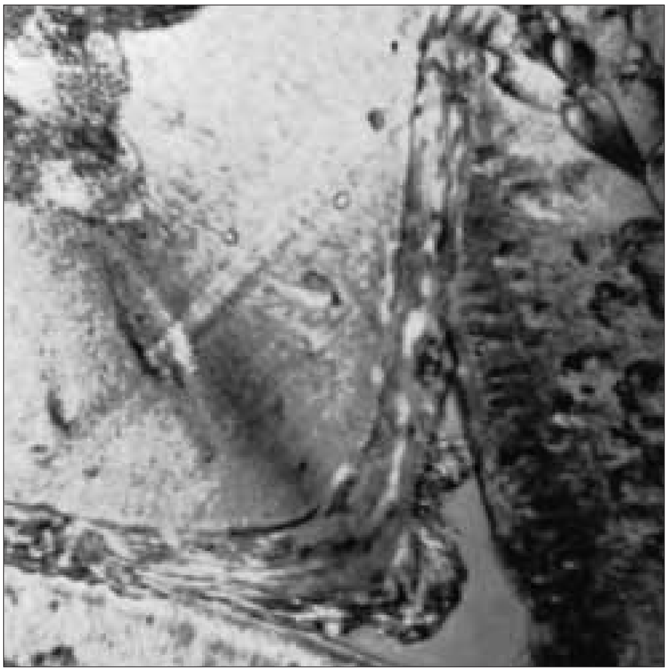


Fig. 10.32 **Microtome of badly welded V-groove**

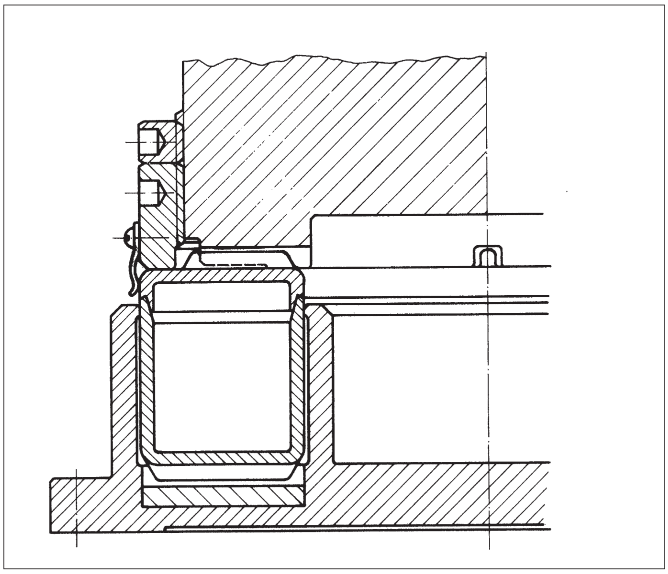


Fig. 10.33 **Welding Double Joints**

Welding Double Joints

The simultaneous welding of two joints, e.g. in the carburettor float in Fig. 10.33, requires special processes and greater care. Practical experience has shown that it is impossible to get good results if the two halves are gripped and driven by tooth crowns. Recesses or ribs must always be provided. It is best if the machine has facilities for adjusting the respective heights of the inner and outer jig faces, so that the weld pressure can be distributed over both joints as required.

In these cases the moment of inertia and the welding pressure must be calculated for the sum of the surfaces. The speed, on the other hand, should be chosen as a function of the smaller diameter.

Fig. 10.33 shows a double-joint float, with appropriate jigs and small ribs for driving the parts. After welding, the spindle does not travel all the way up, so that the next part can be inserted into the jig at rest; only then is the flyweight engaged and accelerated to its operating speed.

The dimensions of the plastic parts should preferably be such that the inner joint begins to weld first, i.e. when there is still an air-gap of about 0,2–0,3 mm on the outer joint (Fig. 10.34).

Welding double joints becomes more difficult as the ratio of the two diameters increases. Although, in practice, parts with an external diameter of 50 mm and an internal diameter of 10 mm have been joined, these are exceptions.

Designs like this should only be undertaken with very great care and after expert advice.

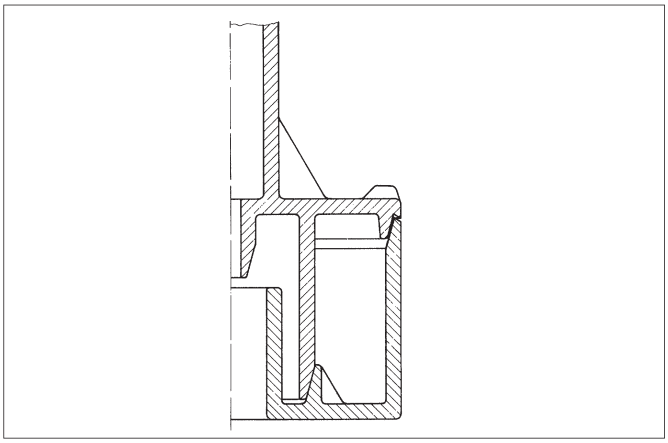


Fig. 10.34 **Design of double joints**

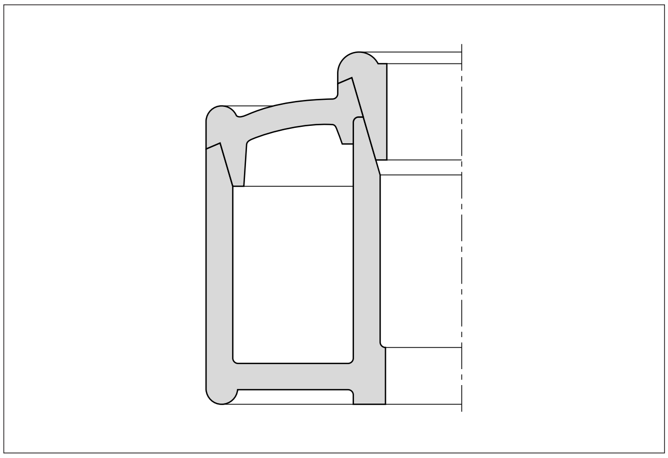


Fig. 10.35 **Double joint split-up in 2 single joints**

In order to avoid all risks, it is better to follow the procedure shown in Fig. 10.35. Here the double joint has been divided into two single ones, which can be welded one after the other and which pose no problem. This solution enables the parts to be gripped with tooth crowns in the normal way, automation is easier, and the total cost is very little more than for one double joint, while avoiding long-winded and expensive preliminary testing.

Welding Reinforced and Dissimilar Plastics

Reinforced plastics can generally be welded just as easily as unreinforced ones. If the filler reduces the coefficient of friction, the weld pressure may sometimes have to be increased so as to reduce the effective weld time.

The weld strength of reinforced plastics is generally lower because the fibres on the surface do not weld together. This is not usually evident in practice, because the joint is not usually the weakest part. If necessary, the weld profile can be enlarged somewhat. In all plastics, glass fibres or fillers reduce tensile elongation, so that stress concentrations are very harmful. Designers pay far too little attention to this fact.

Occasionally one is also faced with the problem of joining plastics of different types, with different melting points. The greater the difference between the melting points, the more difficult welding will be, and one cannot call such a joint a true weld, as it is merely a mechanical adhesion of the surfaces. The strength of the joint will be low. It may even be necessary to have special joint profiles and work with very high weld pressures.

In practice there are very few such applications, and in all these cases the parts are not subjected to stresses. Typical applications are oil-level gauges and transparent polycarbonate spy-holes welded into holders of DELRIN®.

The following test results should give some idea of the possibilities of joining DELRIN® to other plastics.

The float of DELRIN® shown in Fig. 10.13 has a burst pressure of about 4 MPa. If a cap of some other material is welded onto a body of DELRIN®, the burst pressures are as follows:

ZYTEL® 101 (nylon resin)	0,15–0,7 MPa
Polycarbonate	1,2 –1,9 MPa
Acrylic resin	2,2 –2,4 MPa
ABS	1,2 –1,6 MPa

It must be remembered that, in all these cases, the weld forms the weakest point.

Spin Welding Soft Plastics and Elastomers

The softer the plastic, with a few exceptions (e.g. fluoropolymers), the higher the coefficient of friction. Spin welding therefore becomes increasingly difficult with soft plastics, for the following three reasons:

a) The deceleration produced by a high coefficient of friction is so great that the flyweight is unable to produce heat by friction. Much of the energy is absorbed in the deformation of the component, without any relative motion occurring between the joint faces. If the amount of kinetic energy is increased, one is more likely to damage the parts than to improve welding conditions.

   It is sometimes possible to solve this problem by spraying a lubricant onto the joint faces (e.g. a silicone mould release). This reduces the coefficient of friction very considerably at first, so that the usual rotation takes place. The specific pressure is, however, so high that the lubricant is rapidly squeezed out, the friction increases, and the material melts.

b) For soft plastics having a very low coefficient of friction a very much higher specific pressure is needed to produce sufficient heat by friction in a short time. Most components cannot stand such a high axial pressure without being permanently deformed, and there is to date no reliable way of making satisfactory joints between these materials by spin welding.

c) Soft plastic parts are difficult to retain and cannot easily be driven. Transmission of the high torque frequently poses an insoluble problem, particularly since it is scarcely possible to use tooth crowns.

To sum up, it can be said that marginal cases of this sort should be approached only with extreme caution, and that preliminary experimental work is unavoidable.

Figures 10.36–10.38 show only a few selected examples out of the great number of possibilities in this field.

Examples of Commercial and Experimental Mecasonic Spin Machines

Fig. 10.36 **Commercial mecasonic spin machine.**

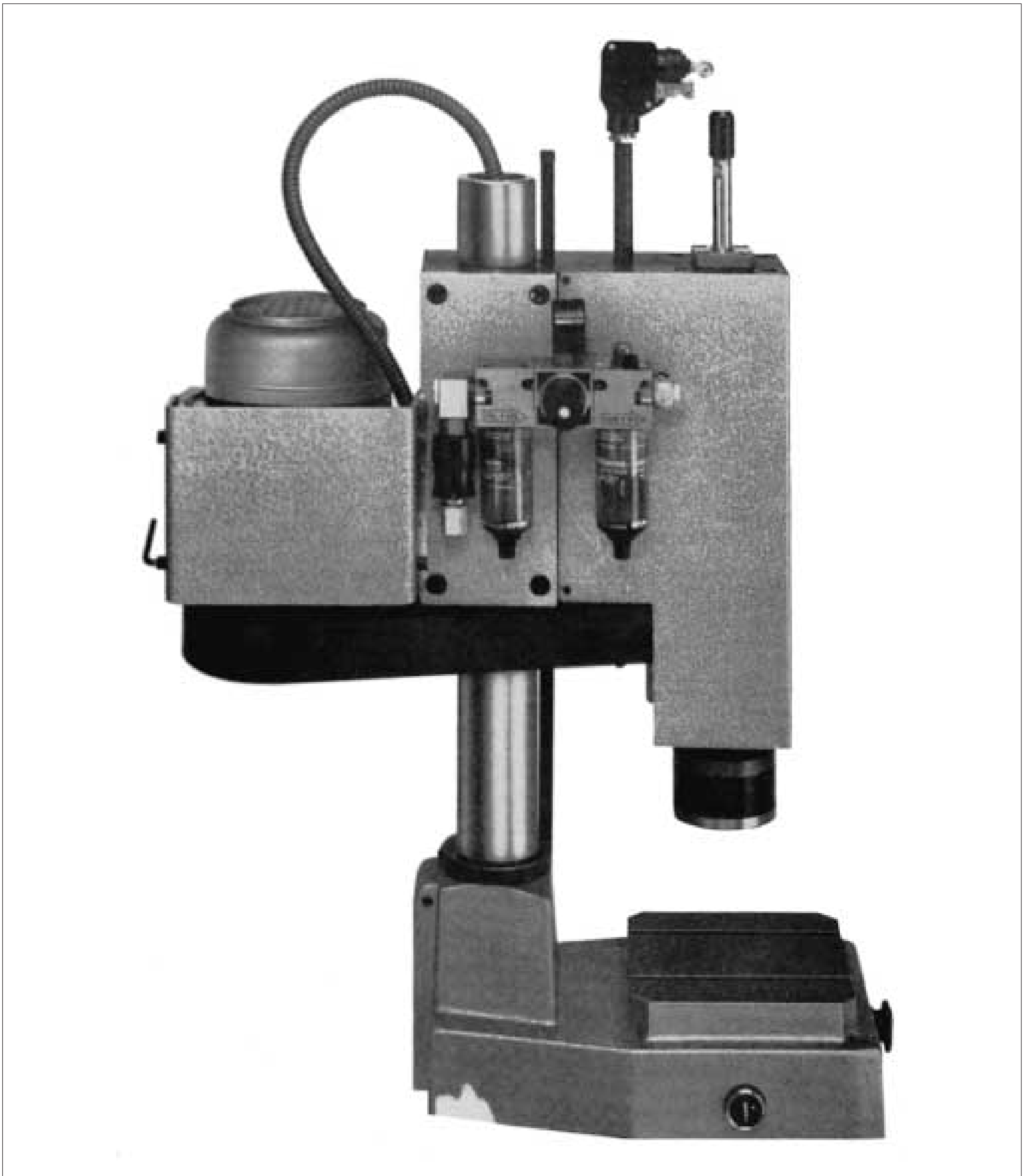


Fig. 10.37 **Commercial bench-type spinwelding machine. The basic model is equipped with a 3-phase squirrel cage motor. The rotating head with the jigs is fixed directly onto the double guided piston rod as shown in Figs. 10.12 and 10.13. The machine can also be supplied with adjustable speed, turntable, automatic cycle control and feeding device.**

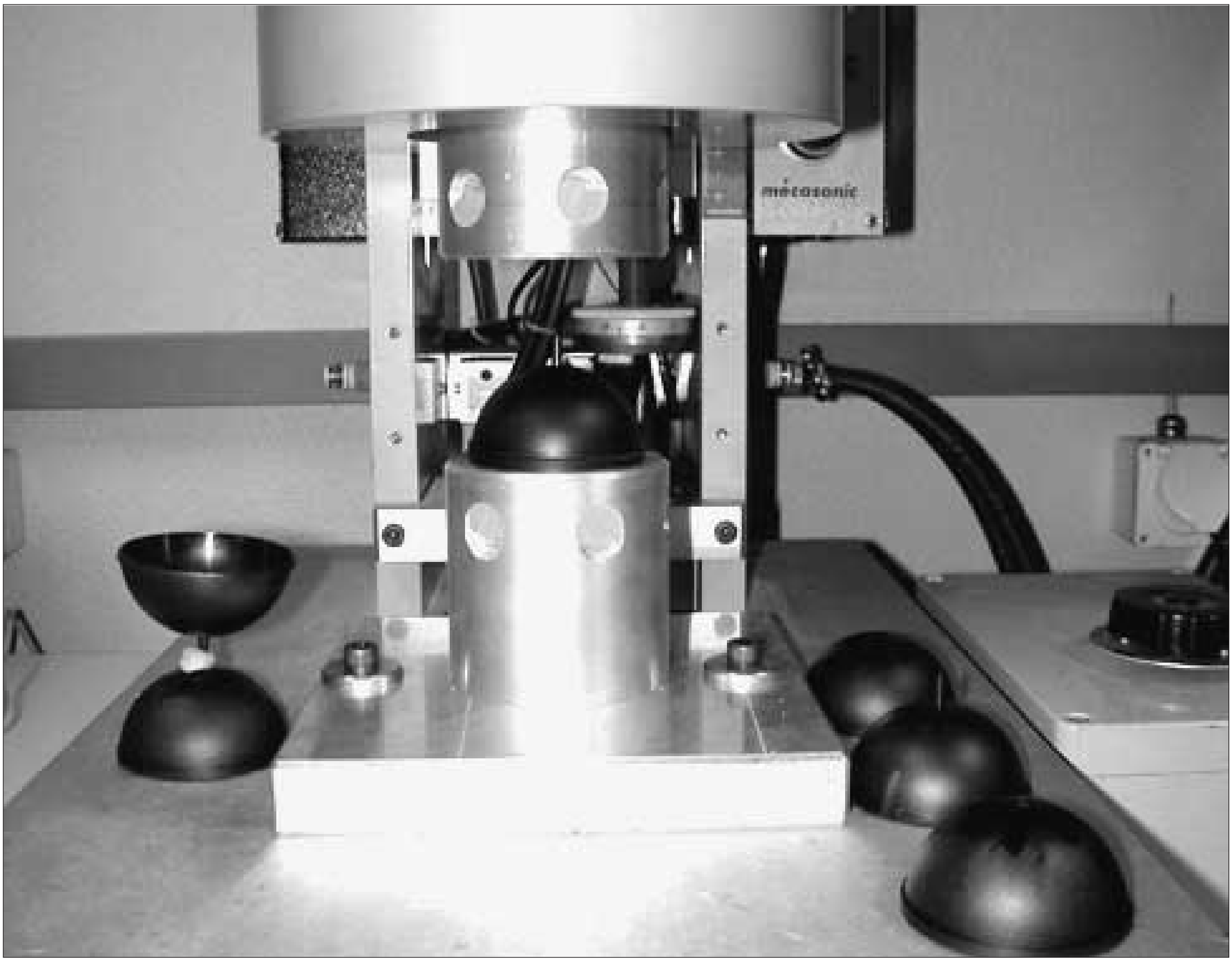


Fig. 10.38 **Spinwelding machine.**

Ultrasonic Welding

Introduction

Ultrasonic welding is a rapid and economical technique for joining plastic parts. It is an excellent technique for assembly of mass produced, high quality products in plastic materials.

Ultrasonic welding is a relatively new technique. It is used with ease with amorphous plastics like polystyrene which have a low softening temperature. Design and assembly, however, require more planning and control when welding amorphous plastics with higher softening temperatures, crystalline plastics and plastics of low stiffness.

This report presents the basic theory and guidelines for ultrasonic welding of parts of DuPont engineering plastics.

Ultrasonic Welding Process

In ultrasonic welding, high frequency vibrations are applied to two parts or layers of material by a vibrating tool, commonly called a ‘‘welding horn’’. Welding occurs as the result of heat generated at the interface between the parts or surfaces.

Equipment required for ultrasonic welding includes a fixture for holding the parts, a welding horn, an electromechanical transducer to drive the horn, a high frequency power supply and a cycle timer. The equipment diagrammed in Fig. 10.41 is described in detail later. Typical ultrasonic welding machines currently available are shown in Fig. 10.42.

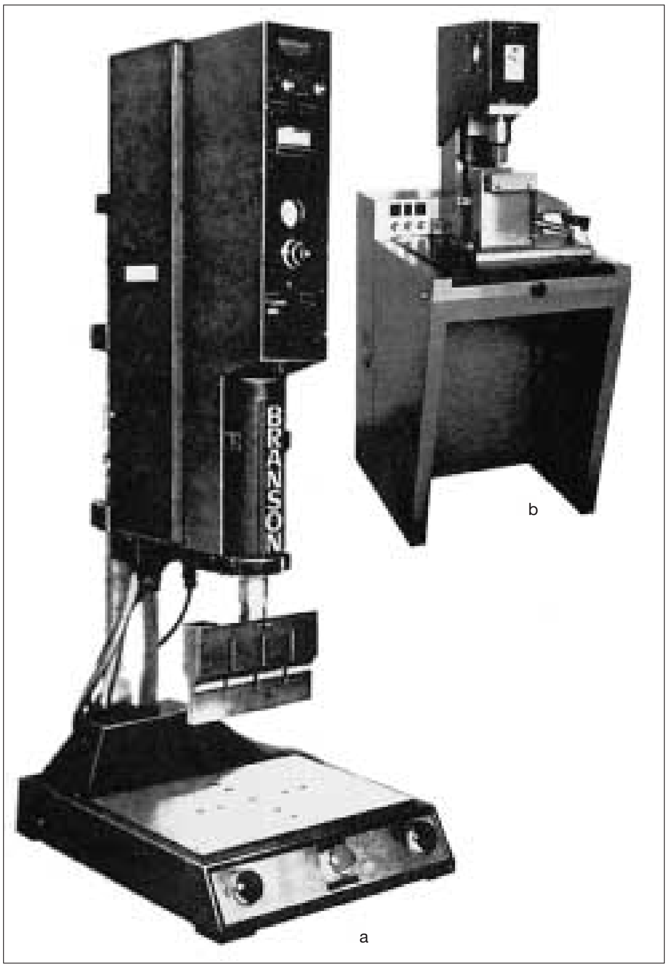


Fig. 10.42 **Typical ultrasonic welding machines, *b* with magnetostrictive transducer, *a* with piezoelectric transducer**

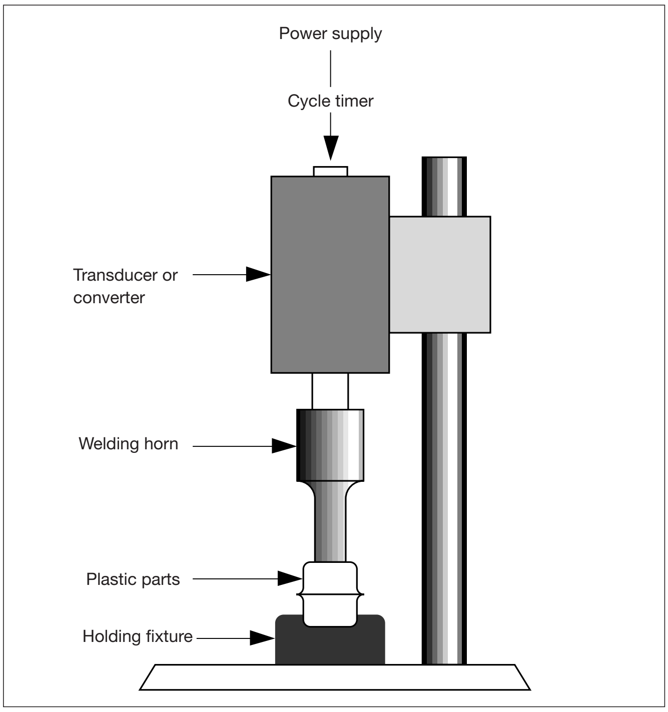


Fig. 10.41 **Components of ultrasonic welding equipment**

Vibrations introduced into the parts by the welding horn may be described as waves of several possible types.

a) Longitudinal waves can be propagated in any materials: gases, fluids or solids. They are transmitted in the direction of the vibration source axis. Identical oscillatory states (i.e. phases) depend on the wave length, both dimensionally and longitudinally. During the operation of mechanical resonators, the longitudinal wave plays almost exclusively the role of an immaterial energy carrier (Fig. 10.43a).

b) Contrary to the longitudinal wave, the transverse wave can be generated and transmitted only in solids. Transverse waves are high frequency electromagnetic waves, light, etc. Shear stresses are required to generate a transverse wave. The latter is moving in a direction perpendicular to the vibration inducing source (transverse vibration). This type of wave must be avoided or eliminated as far as possible, particularly in the ultrasonic welding applications, because only the superficial layer of the welding horn end is submitted to vibrations and thus, energy is not transmitted to the mating surfaces of the energy users (Fig. 10.43b).

c) Curved waves are generated exclusively by the longitudinal excitation of a part. Moreover, the generation of such waves in the application field of ultrasonics requires asymmetrical mass ratios. On the area we are considering, waves of this type lead to considerable problems. As shown on Fig. 10.43c, areas submitted to high compression loads are created at the surface of the medium used, and areas of high tensile strength also appear, meaning the generation of a partial load of high intensity.

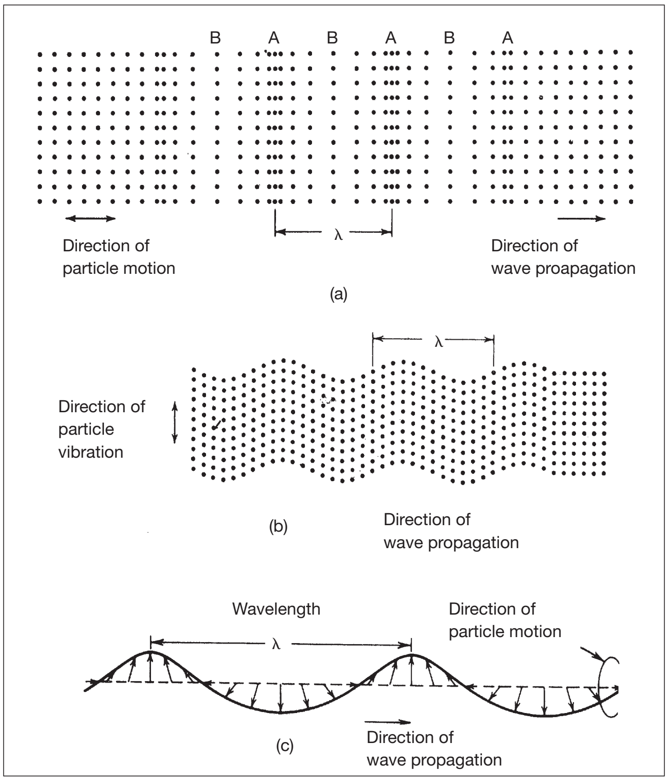


Fig. 10.43 **a) Longitudinal wave.**
b) Transverse wave.
c) Curved wave.

Besides, during the transmission of ultrasonic waves from the transducer to the welding horn, the wave generates a reciprocal vibration from the ceramics to the transducer which could cause the ceramics to break.

When designing welding horns, this situation and also the elimination of the curved waves should be taken carefully into account.

In the welding process, the efficient use of the sonic energy requires the generation of a controlled and localised amount of intermolecular frictional heat in order to purposely induce a certain ''fatigue'' of the plastic layer material at the joint or interface between the surfaces to be welded.

Heat is generated throughout the parts being welded during the welding process. Fig. 10.44 describes an experiment in which a 10 ×10 mm by 60 mm long rod is welded to a flat block of a similar plastic. An ultrasonic welding tool for introducing ultrasonic vibrations into the rod is applied to the upper end of the rod. The block rests on a solid base which acts as a reflector of sound waves travelling through the rod and block. Thermocouples are embedded at various points along the rod. Ultrasonic vibrations are applied for 5 s. Variation of temperature with time at 5 points along the rod are shown in the graph. Maximum temperatures occur at the welding tool and rod interface and at the rod to block interface; however, they occur at different times.

When sufficient heat is generated at the interface between parts, softening and melting of contacting surfaces occur. Under pressure, a weld results as thermally and mechanically agitated molecules form bonds.

Welding Equipment

Equipment required for ultrasonic welding is relatively complex and sophisticated in comparison with equipment needed for other welding processes like spin welding or hot plate welding. A complete system includes an electronic power supply, cycle controlling timers, an electrical or mechanical energy transducer, a welding horn, and a part holding fixture, which may be automated.

a) Power supply

In most commercially available equipment, the power supply generates a 20 kHz electrical output, ranging from a hundred to a thousand or more watts of rated average power. Most recently produced power supplies are solid state devices which operate at lower voltages than earlier vacuum tube devices and have impedances nearer to those of commonly used transducers to which the power supply is connected.

b) Transducer

Transducers used in ultrasonic welding are electromechanical devices used to convert high frequency electrical oscillations into high frequency mechanical vibrations through either piezoelectric or electrostrictive principle. Piezoelectric material changes length when an electric voltage is applied across it. The material can exert a force on anything that tries to keep it from changing dimensions, such as the inertia of some structure in contact with the material.

c) Welding Horn

A welding horn is attached to the output end of the transducer. The welding horn has two functions:

a) it introduces ultrasonic vibrations into parts being welded and

b) it applies pressure necessary to form a weld once joint surfaces have been melted.

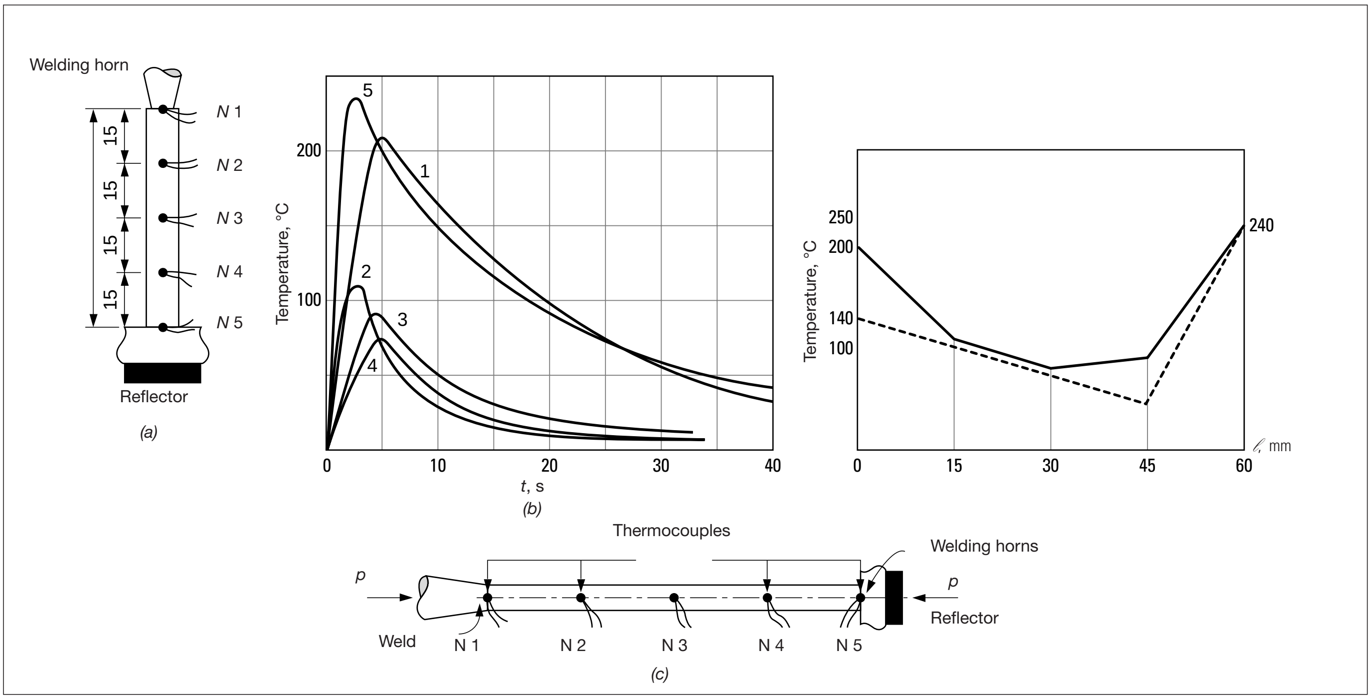


Fig. 10.44 **Variation of temperature along a plastic that has been ultrasonically joined in a tee weld to a plate of the same material.**
a) Schematic diagram of transducer, workpieces and thermocouples.
b) Variation of the temperature with time at various points along the rod.
c) Temperature readings when the weld site temperature is maximum (dashed line) and peak temperatures produced in the rod (solid line).

Plastic parts represent a ‘‘load’’ or impedance to the transducer. The welding horn serves as a means to match the transducer to the load and is sometimes called an impedance matching transformer. Matching is accomplished by increasing amplitude (and hence velocity) of vibrations from the transducer. As a measure of amplification, total movement or double amplitude of the transducer output may be approx. 0,013 mm while vibrations suitable for the welding range can be from 0,05 to 0,15 mm. Amplification or ‘‘gain’’ is one factor in establishing the design of welding horns. Typical welding horns are pictured in Fig. 10.45.

Profiles of stepped, conical, exponential, catenoidal, and fourier horns along with a relative indication of amplitude (or velocity) of the vibration and consequent stress along the horn length elements may be interconnected at stress antinodes, which occur at ends of each ½ wavelength element Fig. 10.46.

Interconnecting horns will increase (or decrease, if desired) the amplitude of vibrations of the last horn in the series. Such an arrangement is shown in Fig. 10.47. The middle horn positioned between transducer and welding horns is usually called a booster horn and is a convenient way to alter amplitude, an important variable in ultrasonic welding.

Care must be exercised in interconnecting horns so that the welding horn is not overstressed in operation, leading to fatigue failure. Some horn materials are better than others in their ability to sustain large motions without failure. High strength titanium alloys rank highest in this. Other suitable horn materials are Monel metal, stainless steel, and aluminium.

Fig. 10.45 **Typical welding horns**

Horn material must not dissipate acoustic energy. Copper, lead, nickel, and cast iron are not suitable horn materials. Horn designs described in Fig. 10.46 are suitable for welding only small pieces in DuPont engineering plastics.

In materials like polystyrene, parts with an overall size larger than the end area of a welding horn can be welded with ‘‘spot’’ horns, shown in Fig. 10.45.

For welding off parts of DuPont engineering plastics, larger than 25 mm in diameter, *the horn end plan should follow joint layout.* Bar and hollow horns, also shown in Fig. 10.47, are useful for welding larger rectangular and circular pieces respectively.

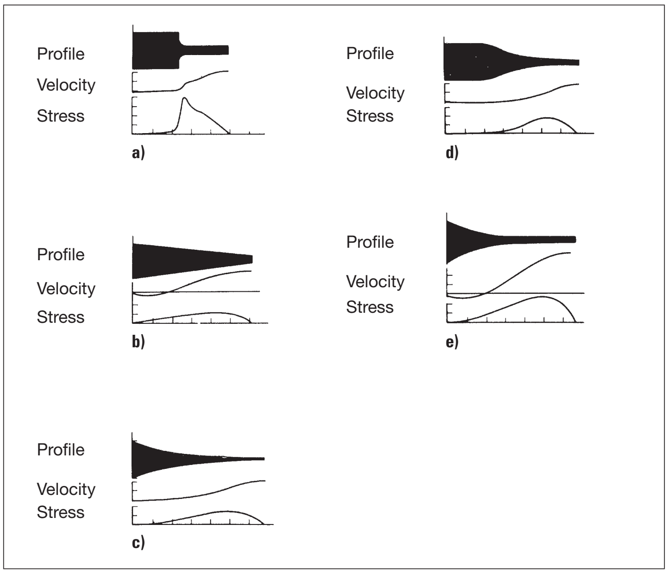


Fig. 10.46 **The profiles of horns for amplifying the output of transducers are as follows: *a)* Stepped. *b)* Conical. *c)* Exponential. *d)* Catenoidal. *e)* Fourier. The variations in particles velocity and stress along he horns are shown below each profile.**

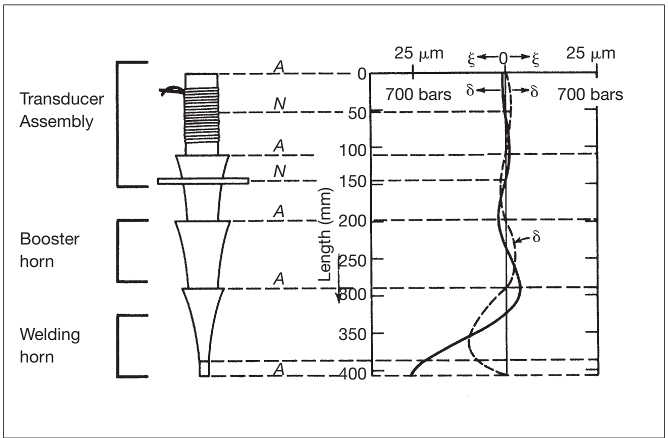


Fig. 10.47 **Tapered or stepped horns may be cascaded to provide increased amplification. The step discontinuities are at antinodal junctions. Measured values of the amplitude and stress at various points along the system are shown. Displacement nodes and antinodes are shown at N and A respectively.**

Further details of this important relationship between part design and horn design are discussed in greater detail under *Part Design.*

The width or diameter of bar or hollow horns is restricted in many cases to a dimension not greater than ¼ the wavelength of the sound in the horn material. As a lateral dimension of the horn exceeds this nominal limitation, lateral modes of vibration in the horn are excited. The horn’s efficiency is thereby reduced. For titanium horns using standard design configurations, lateral dimensions of 65 to 75 mm are limiting. Larger horns may be constructed with slots interrupting lateral dimensions exceeding ¼ the wavelength.

Large parts can also be welded with several clustered horns. With one technique, the horns, each with a transducer, are energized simultaneously from individual power supplies or sequentially energized from one power supply. Another technique utilizes a cluster of horns attached to a single transducer which, when cycled, energizes the horns simultaneously.

For efficient welding, horns must resonate at a frequency very near the nominal 20 kHz operating frequency of the welding system. Thus, welding equipment manufacturers electronically tune welding horns, making subtle variations in horn dimensions to achieve optimum performance. While simple step horns in aluminium may be readily made in the laboratory for the purpose of evaluating prototype welds, such horns are subject to fatigue failure, are readily nicked and damaged, and frequently mark parts being welded. Thus, design and fabrication of more complex horns and horns using more sophisticated materials should be left to equipment manufacturers with experience and capabilities in analytical and empirical design of welding horns.

d) Holding Fixture

Fixtures for aligning parts and holding them stationary during welding are an important aspect of the welding equipment. Parts must be held in alignment with respect to the end of the horn so that uniform pressure between parts is maintained during welding. If the bottom part of the two parts to be welded is simply placed on the welder table, both parts may slide out from under the horn during welding. High frequency vibrations reduce the effect of nominal frictional forces which might otherwise hold pieces stationary. A typical fixture is shown in Fig. 10.48.

Most frequently used fixtures are machined or cast so that the fixture engages the lower part and holds it securely in the desired position. The question of whether a part must be held virtually immovable during welding has not been resolved to date through suitable, controlled experiments. Welding success has been observed in cases where parts were restrained but free to vibrate and when parts were rigidly clamped.

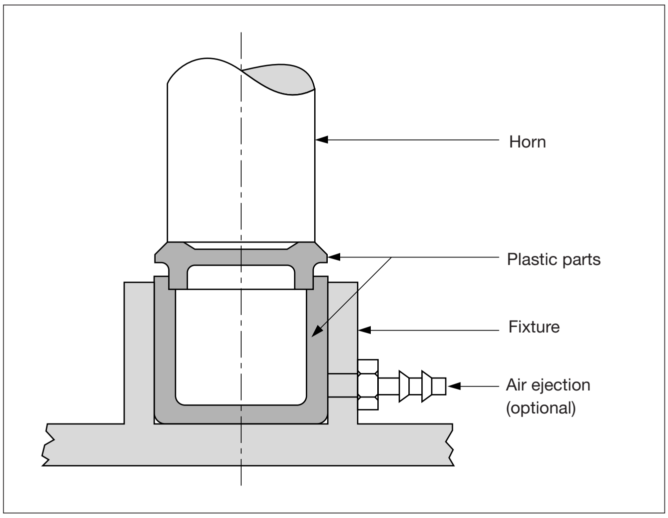


Fig. 10.48 **Support fixture**

The fixture should be rigid so that relative motion is developed between the tool and anvil, thus imparting the working action into the plastic material. This can be achieved by making the anvil short and massive or alternately by tuning the anvil to a quarter wavelength. Trouble can be encountered if the user inadvertently gets the anvil a half wavelength long so that it is resonant at or near 20 kHz. This can permit the anvil to move sympathetically with the horn and seriously limit energy input to the part. If it is slightly off 20 kHz, some annoying squeals and howls will be encoutered as the two frequencies begin to beat.

Flatness or thickness variations in some moulded parts, which might otherwise prevent consistent welding, may be accommodated by fixtures lined with elastomeric material. Rubber strips or cast and cured silicone rubber allow parts to align in fixtures under nominal static loads but act as rigid restraints under high frequency vibrations. A rubber lining may also help absorb random vibrations which often lead to cracking or melting of parts at places remote from the joint area. Another convenient device for establishing initial alignment of the parts and the horn is an adjustable table which can be tilted on two axes in a plane parallel to the end of the welding horn. Thin shim stock is frequently used in lieu of an adjustable table.

High production volume applications frequently require the use of automated part handling equipment and fixtures. For small pieces, vibrating hoppers and feeding troughs are used to feed parts onto an indexing table equipped with multiple fixtures for holding parts. Several welding operations are often performed at sequential positions around the indexing table.

Part Design Considerations

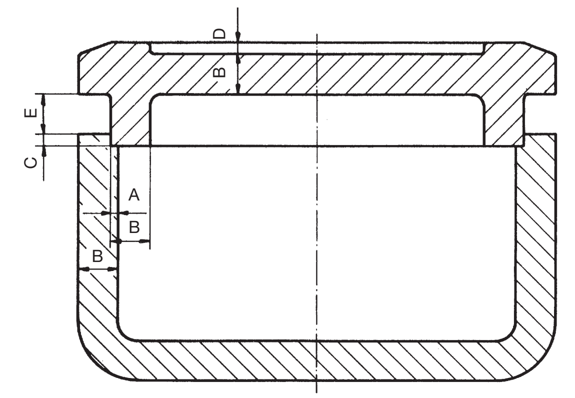
Part design is an important variable, frequently overlooked until tooling has been completed an attempts have been made to weld the firt moulded parts.

a) Joint Design

Perhaps, the most critical facet of part design for ultrasonic welding is joint design, particularly with materials which have a crystalline structure and a high melting point, such as DuPont engineering plastics. It is less critical when welding amorphous plastics. There are two basic types of joints, the shear joint and butt type joint.

Shear Joint

The shear joint is the preferred joint for ultrasonic welding. It was developed by engineers at DuPont's Plastics Technical Centre in Geneva in 1967, and has been used worldwide very successfully in many applications since that time. The basic shear joint with standard dimensions is shown in Fig. 10.49 and 10.50 before, during and after welding.



Dimension A	0,2 to 0,4 mm. External dimensions.
Dimension B	This is the general wall thickness.
Dimension C	0,5 to 0,8 mm. This recess is to ensure precise location of the lid.
Dimension D	This recess is optional and is generally recommended for ensuring good contact with the welding horn.
Dimension E	Depth of weld = 1,25 to 1,5 B for maximum joint strength.

Fig. 10.49 **Shear joint – dimensions**

Fig. 10.51 shows several variations of the basic joint. Initial contact is limited to a small area which is usually a recess or step in either one of the parts for alignment. Welding is accomplished by first melting the contacting surfaces; then, as the parts telescope together, they continue to melt along the vertical walls. The smearing action of the two melt surfaces eliminates leaks and voids, making this the best joint for strong, hermetic seals.

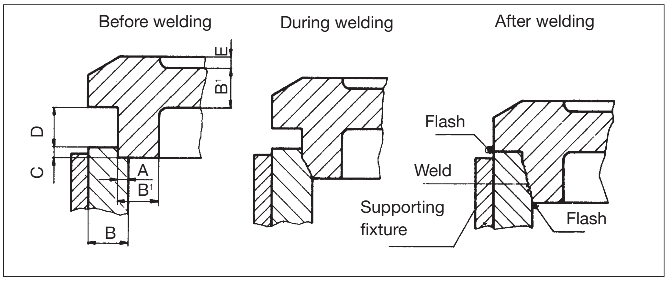


Fig. 10.50 **Shear joint – Welding sequence**

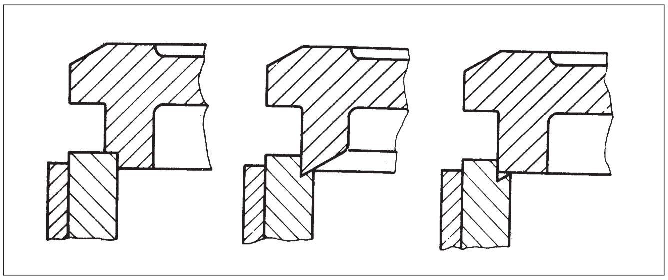


Fig. 10.51 **Shear joint – Variations**

The shear joint has the lowest energy requirement and the shortest welding time of all the joints. This is due to the small initial contact area and the uniform progression of the weld as the plastic melts and the parts telescope together. Heat generated at the joint is retained until vibrations cease because, during the telescoping and smearing action, the melted plastic is not exposed to air, which would cool it too rapidly.

Fig. 10.52 is a graph which shows typical weld results using the shear joint. It is a plot of weld time vs. depth of weld and weld strength. Depth and strength are directly proportional.

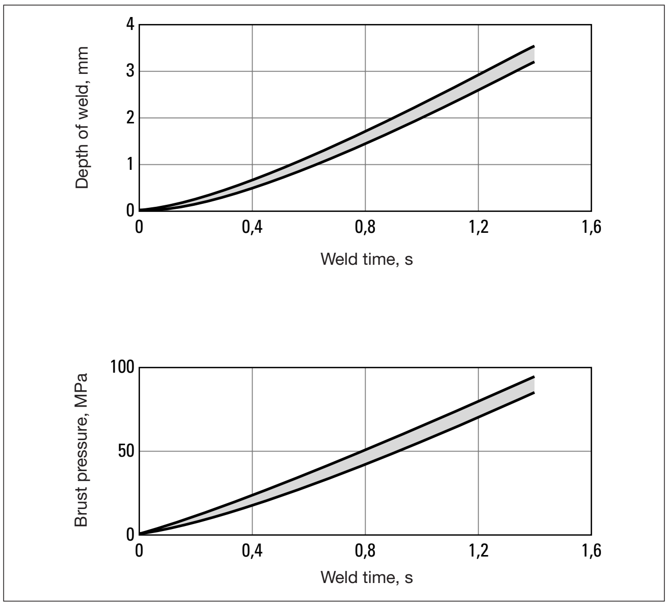


Fig. 10.52 **Shear joint – Typical performance**

Weld strength is therefore determined by the depth of the telescoped section, which is a function of the weld time and part design. Joints can be made stronger than the adjacent walls by designing the depth of telescoping 1,25 to 1,5 times the wall thickness to accomodate minor variations in the moulded parts (see E on Fig. 10.49).

Several important aspects of the shear joint must be considered; the top part should be as shallow as possible, in effect, just a lid. The walls of the bottom section must be supported at the joint by a holding fixture which conforms closely to the outside configuration of the part in order to avoid expansion under the welding pressure.

Non continuous or inferior welds result if the upper part slips to one side or off the lower part, or if the stepped contact area is too small. Therefore, the fit between the two parts should be as close as possible before welding, but not tight. Modifications to the joint, such as those shown in Fig. 10.53, should be considered for large parts because of dimensional variations, or for parts where the top piece is deep and flexible. The horn must contact the joint at the flange (nearfield weld).

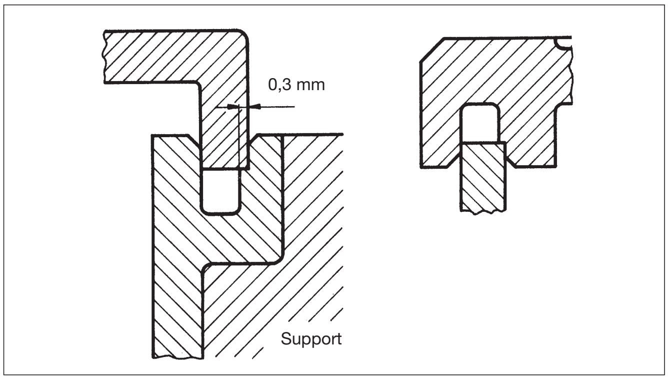


Fig. 10.53 **Shear joint – Modifications for large parts**

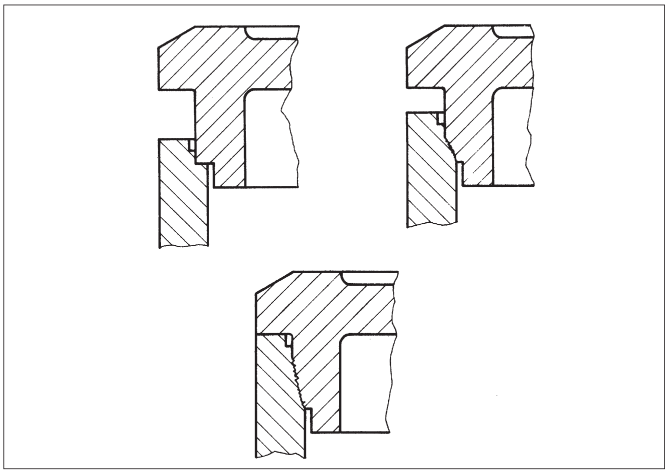
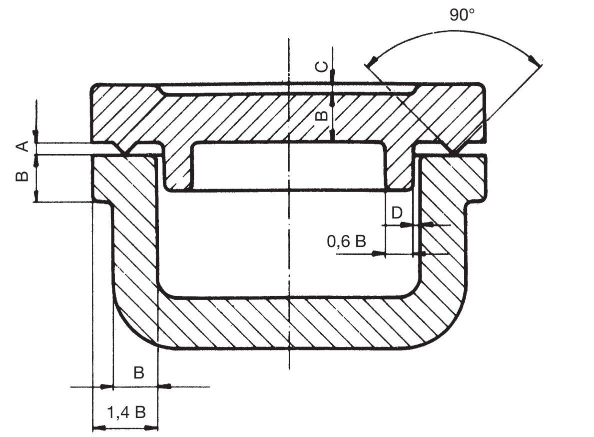


Fig. 10.54 **Shear joint – Flash traps**

Allowance should be made in the design of the joint for the flow of molten material displaced during welding. When flash cannot be tolerated for aesthetic or functional reasons, a trap similar to the ones shown in Fig. 10.54 can be designed into the joint.

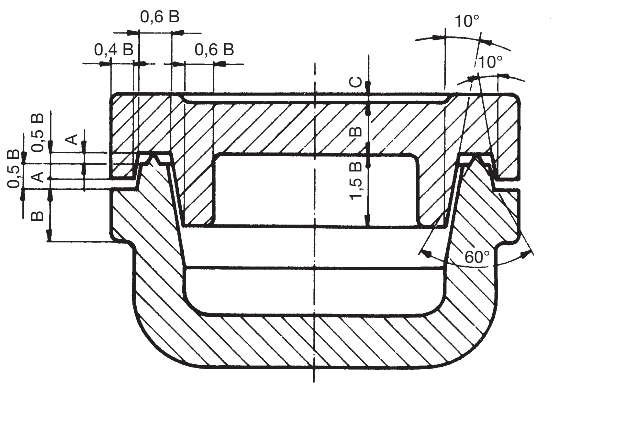
Butt Joint

The second basic type of joint is the butt joint which is shown in Fig. 10.55, 10.56 and 10.57, with variations. Of these, the tongue-in-groove provides the highest mechanical strength. Although the butt joint is quite simple to design, it is extremely difficult to produce strong joints or hermetic seals in the crystalline resins.



Dimension A 0,4 mm for B dimensions from 1,5 to 3 mm and proportionally larger or smaller for other wall thicknesses.
Dimension B General wall thickness.
Dimension C Optional recess to insure good contact with welding horn.
Dimension D Clearance per side 0,05 to 0,15 mm.

Fig. 10.55 **Butt joint with energy director**



Dimension A 0,4 mm for B dimensions from 1,5 to 3 mm and proportionally larger or smaller for other wall thicknesses.
Dimension B General wall thickness.
Dimension C Optional recess to insure good contact with welding horn.

Fig. 10.56 **Tongue-in-groove**

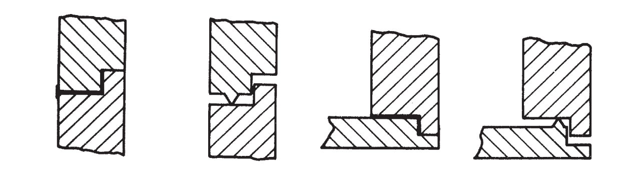


Fig. 10.57 **Butt joint – Variations**

Strong joints can be achieved with amorphous resins, however, it may be difficult to obtain hermetic seals in complex parts.

The main feature of the butt joints is a ‘‘V’’ shaped bead or ‘‘energy director’’ on one of the two mating surfaces which concentrates the energy and limits initial contact to a very small area for rapid heating and melting. Once the narrow area begins to soften and melt, impedance drops and further melting occurs at a faster rate. The plastic in the energy director melts first and flows across the surfaces to be joined. Amorphous plastics have a wide, poorly defined softening temperature range rather than a sharp melting point. When the plastic flows, sufficient heat is retained in the melt to produce good fusion over the entire width of the joint.

DELRIN®, ZYTEL®, MINLON® and RYNITE® are crystalline resins with no softening before melting and a sharp melting point and behave different than amorphous resins. When the energy director melts and flows across the surfaces, the melt being exposed to air can crystallize before sufficient heat is generated to weld the full width of the joint. It is necessary, therefore, to melt the entire joint surface before significant strength can be obtained. (In the case of ZYTEL®, exposure of the high temperature melt to air can cause oxidative degradation which results in brittle welds). This phase of the weld cycle is very long as can be seen in Fig. 10.58 and 10.59, which are graphs showing typical weld sequences for parts of DELRIN® and ZYTEL® using the basic butt joint.

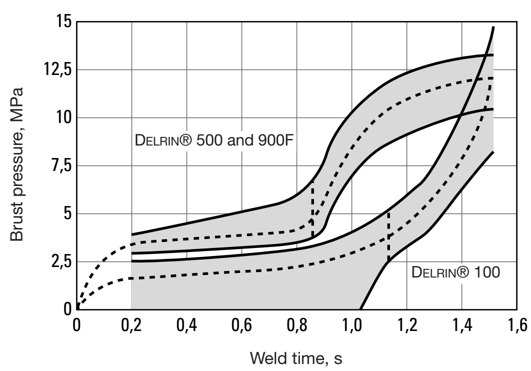


Fig. 10.58 **Butt joint – Typical performance, burst pressure vs. weld time**

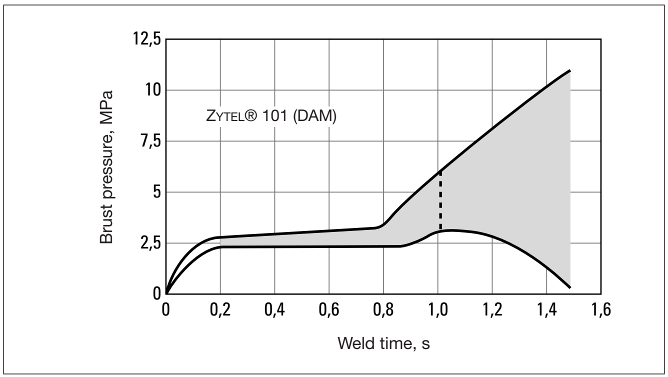


Fig. 10.59 **Butt joint – Typical performance, burst pressure vs. weld time**

The dotted lines indicate the weld time at which an objectionable amount of flash occurs. This flash is a limiting factor in most applications. Beyond this time, results are extremely variable, especially with ZYTEL®.

b) General Part Design

The influence of overall part design on ultrasonic welding has not been fully determined. However, some generalizations can be made about certain aspects of part design and their effect on the success of welding.

Determining the location at which the welding horn will contact a part is a very important aspect of part design. Some of the considerations for location have already been mentioned in the discussion of the various joint designs.

There are two methods of welding, far field and near field as illustrated in Fig. 10.60. They refer to the point of horn contact relative to the distance from the joint. Best welding results for all plastics are obtained with near field weling. Therefore, wherever possible, parts should be designed for horn contact directly above and as close to the joint as possible.

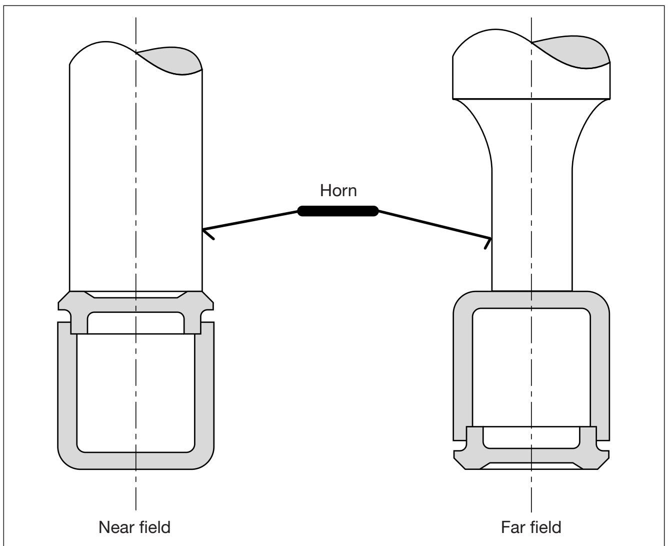


Fig. 10.60 **Near field and far field welding**

In far field welding, the horn contacts the upper part at a distance from the joint and relies on the plastic to transmit the vibrations to the joint. Rigid, amorphous plastics transmit the vibrations to the joint. Rigid, amorphous plastics transmit the ultrasonic energy very well. Although rigid plastics such as DELRIN®, ZYTEL®, MINLON® and RYNITE® have a more crystalline structure and can absorb vibrations without creating appreciable heat rather than transmitting them, they are more difficult to weld by the far field technique.

Soft plastics such as polyethylene can only be welded by the near field technique. Because they have a high acoustic damping factor, they strongly attenuate the ultrasonic vibrations upon entry into the material. If the joint is too far from the horn, the energy is not transmitted to the joint and the plastic melts at the interface with the horn.

Plastics are poor transmitters of shear waves. This fact makes welding more difficult when the geometry of the upper piece is complex. Vibrations are partially attenuated or dissipated at bends, angles or discontinuities such as holes in the structure between the horn and the joint. These features should be avoided.

To maximize transmission of vibrations, parts should be designed with a flat contacting surface for the welding horn. This surface should be as broad as possible and continous around the joint area. Interruptions in contact between the horn and the part may result in weld interruptions.

Fillets are desirable for all parts designed for ultrasonic welding. Since the entire structure of both halves being welded is subjected to vibrations, a very high level of stress occurs at sharp internal corners. This frequently results in fracture or sporadic melting. Fillet radii consistent with good moulding and structural design practice are suggested.

Because of pervasive vibrations, care is suggested when welding parts with unsupported appendages and large spans. Vibrations may be severe enough to literally disintegrate a cantilevered spring, for example, extending from the wall section of a part. Measures, such as rubber lined fixtures or a rubber damper attached to the welding horn, may be taken to dampen such vibrations. This phenomenon can be used to advantage: experiments have shown that moulded parts can be degated quickly and with a smooth finish by applying ultrasonic energy to the runners.

Ultrasonic Welding Variables

The major ultrasonic welding variables are *weld time, hold time, pressure and amplitude of vibration*. Suggested procedures for optimizing them are found under b) on page 117.

a) Weld Time

Weld time is the period during which vibrations are applied. The correct weld time for each application is determined by trial and error. It is important to avoid over-welding. In addition to creating excessive flash which may require trimming, this can degrade the quality of the weld and lead to leaks in parts requiring a hermetic seal. The horn can mar the surface. Also, as was shown in Fig. 10.44 melting and fracture of portions of the parts away from the joint area may occur at longer weld times, especially at holes, weld lines, and sharp corners in moulded parts.

b) Hold time

Hold time is a nominal period after welding during which parts are held together and allowed to solidify under pressure without vibrations. It is not a critical variable in most applications; 0,3 to 0,5 seconds are usually sufficient for most applications unless an internal load tends to disassemble the welded parts, such as a coil-spring compressed prior to welding.

c) Amplitude of Vibrations

The physical amplitude of vibrations applied to the parts being welded is an important process variable. High amplitude of vibration of appr. 0,10 to 0,15 mm peak-to-peak is necessary to achieve efficient and rapid energy input into DuPont engineering plastics. Because the basic transducer delivers its power at high force and low amplitude, the amplitude must be stepped up before reaching the tool tip. The horn design usually includes amplitude transformation inherent in tapering or stepping its profile down to a small diameter. Where the part geometry requires a large or complex tip shape, this amplification may not be possible in the horn. In this case, amplification can be conveniently achieved in most commercial systems by use of an intermediate tuned section called a booster horn. Boosters up to 2,5:1 amplification are commercially available. Negative boosters to 0,4:1 for horns having too high an amplitude for a given application are also available. Boosters which provide a 2:1 or 2,5:1 amplification are typically required, except for small parts which permit the use of high gain horns.

Increasing amplitude improves weld quality in parts designed with shear joints. With butt type joints, weld quality is increased and weld time is reduced with increasing amplitude.

d) Pressure

Weld pressure provides the static force necessary to ‘‘couple’’ the welding horn to the plastic parts so that vibrations may be introduced into them. This same static load insures that parts are held together as the melted material in the joint solidifies during the ‘‘hold’’ portion of the welding cycle.

Determination of optimum pressure is essential for good welding. If the pressure is too low, the equipment is inefficient leading to unnecessarily long weld cycles. If it is too high in relation to the horn tip amplitude, it can overload and stall the horn and dampen the vibrations.

The overall amplitude gain provided by the booster and the horn is analogous to the load matching provided by the gear ratio between an automobile engine and its rear wheels. In ultrasonic welding, low pressure is required with high amplitude and high pressure is required with low amplitude.

This is shown in the graph in Fig. 10.61. It is a plot of weld efficiency vs. weld pressure for three levels of amplitude obtained by use of the boosters indicated. There are several methods for measuring welding efficiency.

These are fully described in the next chapter. In addition to showing the relationship of amplitude and pressure, another very important effect is shown. As amplitude increases, the range of acceptable pressure decreases. Therefore, finding the optimum pressure is most critical when the amplitude is high.

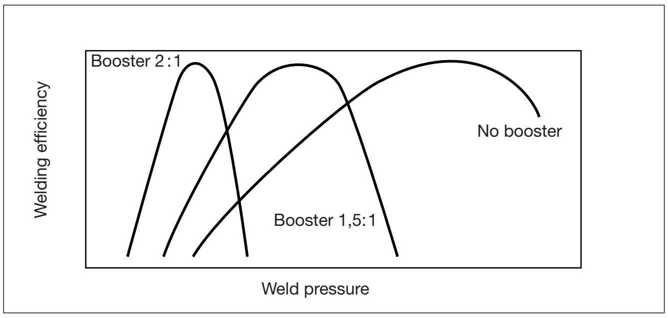


Fig. 10.61 **Welding efficiency vs. amplitude and pressure**

Guide to Equipment Operation

Proper operation of welding equipment is critical to the success of ultrasonic welding. The following comments are suggested as a guide to the use of ultrasonic welding machines with parts of DuPont engineering plastics.

a) Initial Equipment Setup

Horn Installation

The transducer, welding horn, and booster horn (if needed) must be tightly bolted together to insure efficient transmission of vibrations from the transducer to the parts. The end surfaces of the transducer output and horns are usually flat to within several microns. However, to insure efficient coupling heavy silicone grease or a thin brass or copper washer cur from 0,05 or 0,08 mm shin stock is used between horns. Long spanner wrenches are used to tighten horns. Care must be exercised when tightening horns, so as not to turn the transducer output end. Such turning may pull the electrical leads from the transducer.

After installation of the horns, some welders require manual tuning of the electronic power supply. Small, but important adjustments to the frequency of power supply are made to exactly match its frequency to that of the horns. Some welders accomplish this tuning automatically. The operations manual for a particular welder will indicate required tuning procedures, if any. This procedure must be repeated each time a horn or booster is changed.

If the amplitude of vibration of a horn is not known, it may be determined quite simply with either a microscope or a dial indicator. A booster should not be used if only the amplitude of the welding horn is to be determined. A 100 × microscope with a calibrated reticule in the eye piece is suitable for making optical measurements. When magnified, the machined surface of the horn appears as bright and dark peaks and valleys respectively. When the horn is vibrating, a peak will blur out into a streak and the length of the streak is the peak-to-peak amplitude or total up and down excursion of the end of the horn.

A machinist's dial indicator may be used to measure ‘‘amplitude’’ or half the total movement of the horn. The dial indicator is positioned with an indicator tip contacting the bottom surface of the horn and in an attitude such that the tip moves in a vertical direction. The indicator is set to zero with the horn stationary. When the horn is vibrating, it will deflect the indicator tip downward.

Since the indicator cannot respond to the horns rapid movement, the indicator tip will stay in this downward position, accurately measuring the half cycle movement of the horn. These measurements are made when the horn is not welding the parts. Even though the amplitude of vibration is reduced somewhat under peak welding pressure, the ‘‘unloaded’’ amplitude is still a useful measure of this important welding parameter.

Part and Fixture Alignment

The parts, fixture, and welding horn must be physically aligned so that the pressure and vibrations are uniformly and repeatedly applied. As was shown in Fig. 10.41, the welding transducer is attached to a stand. The transducer assembly slides up and down in relation to the stand and is powered by a pneumatic cylinder. By reducing pressure, the transducer assembly may be easily moved by hand. With the parts placed in a suitable holding fixture, the horn is pulled down by hand while the fixture is positioned and secured.

Alignment of the parts and fixture in a plane parallel to the end plane of the horn may be achieved in several ways. In one, a sheet of fresh carbon paper is placed with the carbon side against a sheet of plain paper and both are positioned between the welding horn and parts. ‘‘Weld-time’’ is set to the minimum possible time. When the horn vibrates against parts, an impression is formed on the plain paper, and the variation of the ‘‘darkness’’ of impression indicates pressure variation. This method can be used with both shear and butt type joints.

Parallel alignment is less critical with the shear joint than with butt type joints. Because of the depth of weld and the smearing action, minor variations do not significantly affect the strength or sealing characteristics of the weld. For this same reason, a higher degree of warpage in parts can be tolerated with this joint. Parallel alignment is of major importance when dimensions of the assembled parts are critical.

Another technique can be used for butt type joints. First, the welder is operated with weld-time set to produce a light flash at the joint between the parts. The fixture may then be shimmed or adjusted so that flash is produced uniformly around the joint.

All welding machines have a means for adjusting the transducer assembly height above the work table. Height must be adjusted so that the downward stroke of the transducer assembly is less than the maximum stroke capability of the welding machines. Otherwise, insufficient or erratic pressure will be developed during welding.

Some welding machines require the setting of a trip switch, once horns have been intalled and the parts and fixture are aligned. A trip switch closes the circuit which applies power to the transducer and simultaneously starts the ‘‘weld-time’’ timer. The trip switch should be set so that the welding machine is turned on slightly before the horn makes contact with the parts. Otherwise, the system may stall when trying to start against full pressure. Most recently manufactured welding machines are turned on by a pressure sensitive switch and do not require switch height adjustment.

b) Optimizing Welding Cycle

Amplitude, welding pressure, and weld time must be adjusted and optimized for each application. Each variable is studied independently by welding several groups of parts at a number of settings with all other vriables held constant. The results of each weld are observed, measured, and recorded, and the optimum value is determined.

There are several measures of weld quality of welding efficiency which can be used to optimize welding conditions. These include measurement of depth of weld (with shear joint), physical tests on welded parts such as burst strength or break strength, and observation of power supply load or efficiency meters. The measure selected will depend on the end-use requirements of the parts.

For maximum accuracy physical tests should be considered. This is especially true for pressurized containers such as gas lighter tanks and aerosol containers where burst pressure tests are essential. These tests are time and labour consuming and should be used only when necessary.

The depth of the weld (or height of the welded parts) can be measured when welding with the shear joint. This a less expensive and time-consuming method which provides sufficient accuracy for optimizing conditions. Excellent correlation has been established between depth of the weld and weld strength.

Most power supplies are equipped with power meters which give an indication of the efficiency of the welding. Observing the meter level during welding is a simple technique, but is the least accurate.

Pressure and Amplitude

The first step in optimizing conditions is to select a welding horn and booster or coupling bar combination which gives the necessary amplitude (peak-to-peak). It is helpful but not essential to know the specific amplitude of the welding horn or the combination of horns.

To establish optimum conditions of pressure and amplitude, weld time should be held constant. For shear joints, a relatively short time is suggested (0,03 to 0,6 seconds). A long weld time is suggested for butt-type joints.
Hold time should also be held constant. It is not a critical variable. The same value can be used for all setup and production welding.

A number of parts are welded at several weld pressure settings, for example, 0,15 – 0,20 – 0,25 – 0,30 – 0,35 MPa. The values of welding efficiency (meter, depth, or physical test) can be plotted as shown in Fig. 10.61 to establish the optimum pressure for the selected amplitude. In actuality, the plot will not be a line but a narrow band which represents a range of values. The optimum pressure is indicated by the highest and most narrowly defined portion of the data. To further pinpoint optimum pressure, it may be desirable to weld additional samples in the range of this pressure level.

For example, if the peak appears to be between 0,15 to 0,25 MPa samples should be welded at 0,18 and 0,22 MPa.

Optimum amplitude is determined by repeating the above procedure using amplitude greater and less than the initial amplitude. This is most easily accomplished by changing boosters. If there appears to be little or no difference among the peaks of serveral amplitudes (as may be the case, with the shear joint when the depth of weld is measured), use the highest amplitude.

Weld time

The correct weld time is the last setting to be determined. Using the selected amplitude and optimum pressure for that amplitude, parts are welded at weld time settings higher or lower than the initial value until the required depth of weld, joint strength, or appearance is achieved.

In selecting welding conditions, appearance of parts is frequently important. In many cases, high strength cannot be achieved without formation of visible external weld flash unless flash traps are designed into the joint (refer section on Joint Designs). Flash trimming may be necessary in some applications.

The procedure for optimizing welding conditions may be considerably shortened on the basis of experience with previous welding applications.

Welding Performance

a) Influence of Material Properties

Properties of plastics influence success in ultrasonic welding. Often properties which dictate the selection of a material for a particular application are properties which make welding more difficult, such as high melt temperature or crystallinity. The stiffness of the material being welded is an important property which may be influenced by environmental temperature and moisture. Of greater importance are influences of pigments, mould release agents, glass fillers, and reinforcement fibres.

DELRIN® Acetal Resin

DELRIN® is a highly crystalline plastic with a high, sharp melting point, high strength, hardness and stiffness at elevated temperatures. Of both ‘‘flow’’ grades of DELRIN®, part of DELRIN® 500 weld easier than parts of the higher melt viscosity DELRIN® 100. The difference is very slight with the shear joint but more pronounced with the butt type joints. DELRIN® 570, a glass filled composition, may also be ultrasonically welded. Lubricants and pigments negatively influence welding as noted below. Atmospheric moisture does not appear to influence the welding of parts of DELRIN®.

ZYTEL® Nylon Resin

ZYTEL® nylon resins are also crystalline plastics with high melting points. Variations in welding performance have been observed among the families of ZYTEL® resins.

Parts moulded of ZYTEL® 101 and other basic 66 nylons can be welded with the same degree of ease as parts of DELRIN®. An additional requirement, however, is that parts must be in a ‘‘dry-as-moulded’’ condition. The influence of moisture on the welding of ZYTEL® parts is discussed in greater detail below.

Parts moulded of ZYTEL® 408 and other modified 66 nylons may be ultrasonically welded but with slightly greater difficulty than ZYTEL® 101. The slightly lower stiffness of these resins may cause some problems with marring and formation of flash under the welding horn.

Due to low dry-as-moulded stiffness, parts moulded of ZYTEL® 151 and other 612 nylons can be welded but with slightly more difficulty than ZYTEL® 101. These resins are noted for their very low moisture absorption. Therefore, in all but the most critical applications it is not necessary to keep the parts dry before welding.

Parts of glass reinforced ZYTEL® nylon can also be ultrasonically welded; sometimes with greater ease than the unreinforced material. Resins in the ZYTEL® nylon 79G, 70G series may be welded with weld strengths equal only to that of the base unreinforced material because no glass reinforcement occurs at the weld. For this reason, if the strenght of the joint weld is required to equal that of the reinforced resin, the joint area must be increased in relation to the wall thickness. This can be easily done with the shear joint.

Of the glass reinforced ZYTEL® resins, ZYTEL® 79G13 is the most difficult to weld. At the 13% glass reinforcement level, excessive marring and flashing under the welding horn may still occur.

MINLON® engineering thermoplastic resin

The comments made before about glass reinforced ZYTEL® are valid for MINLON®, matrix of the resin being the same. MINLON® contains 40% mineral filler which allows an outstanding welding speed (30–50% faster than DELRIN® 500). However we have noticed a certain sensitivity of moulded parts to sharp angles, badly cut gates or any other weak areas which can break under ultrasound and particular attention must be paid to the design of the part, more especially for MINLON® 10B140.

RYNITE® thermoplastic polyester resin

Because of its high stiffness this glass-reinforced polyester resin is easy to weld. It is preferable to always use a step-joint for such a resin which is often used in very demanding applications (sometimes even at high temperatures). An over-welding time may generate burned material in the sonotrode area.

b) Effect of Moisture on ZYTEL®

Nylon resins absorb somewhat more moisture from the air after moulding than most other plastics. When released from joint surfaces during welding, moisture causes poor weld quality. For best results, parts of ZYTEL® should either be ultrasonically welded immediately after moulding or kept in a dry-as-moulded condition prior to welding. Exposure of 1 or 2 days to 50% relative humidity at 23° C is sufficient to degrade weld quality by 50% or more as shown in Fig. 10.62. Welding parts at longer than normal weld times may offset this loss of weld quality, but often at the expense of heavy weld flash and marring under the welding horn. As was shown in Fig. 10.44, the part temperature near the horn approaches that at the joint during welding, and therefore lengthening weld cycles may cause severe problems.

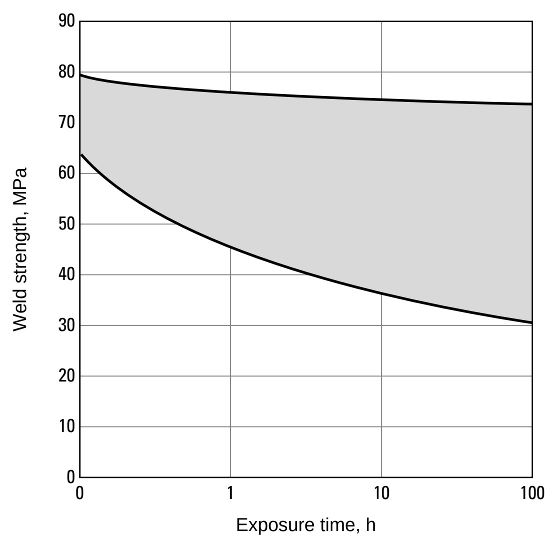


Fig. 10.62 **Effect on weld strength vs. time of exposure (prior to welding) to air at 23° C, 50% R.H. for ZYTEL® 101 NC010 nylon**

Parts may be kept dry for periods up to several weeks by sealing them in polyethylene bags immediately after moulding. For longer periods, greater protective measures must be taken such as the use of jars, cans, or heat sealable moisture barrier bags. Parts which have absorbed moisture may be dried prior to welding in a drying oven. Procedures for this are described in ZYTEL® design and moulding manuals.

c) Pigments, Lubricants, Mould Release Agents

The influence of pigment systems on ultrasonic welding can be considerable. Most pigments are inorganic compounds and are typically used in concentrations ranging from 0,5% to 2%. With welding equipment set at conditions which produce quality welds in unpigmented parts, the quality of welds in pigmented parts may be markedly lower. Poor quality is reflected in welds of low strength and greater brittleness.

The mechanism by which pigments influence welding has not been identified to date. The presence of pigments appears to influence the means of heat generation at the joint. Often lower weld quality may be offset by welding pigmented parts at longer weld times than anticipated for unpigmented parts. Weld times may have to be increased by 50% or more. However, these longer weld times may produce undesirable effects such as the formation of excess weld flash and marring unter the welding horns.

When ultrasonic welding is contemplated for assembling parts which must be moulded in pigmented material, test welding of moulding prototypes is recommended to establish the feasibility of the application. In many commercial applications, weld strength and toughness are not critical requirements. Use of dye colouring systems, which do not significantly effect ultrasonic welding, may offer an alternative solution.

The above comments apply also to the welding of materials with externally or internally compounded lubricants and mould release agents. Relatively small quantities of such materials appear to adversely affect the means of heat generation in the joint during welding. While the increase in weld time may offset some of this influence, the consequent problems mentioned above may occur. If spray-on mould release agents are used in moulding of otherwise unlubricated moulding material, these parts should be thoroughly cleaned prior to welding.

Other Ultrasonic Joining Techniques

a) Ultrasonic Heading

Ultrasonic equipment can be used for heading or staking to tightly join parts of DuPont engineering plastics to parts of dissimilar materials, usually metal. A stud on the plastic part protrudes through a hole in the second part. A specifically contoured horn contacts and melts the top of the stud and forms a rivet-like head. This produces a tight joint because there is no elastic recovery as occurs with cold heading.

Suggested horn and part design are shown in Fig. 10.63. The volume of displaced plastic equals the cavity of the horn. Many variations of the design are possible to fit particular applications.

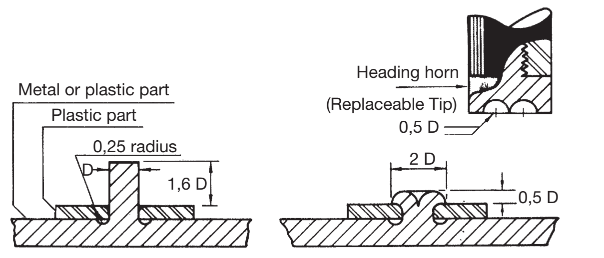


Fig. 10.63 **Ultrasonic heading**

Where possible, an undercut radius at the root of the stud and a radius on the hole of the part to be attached should be included. This increases the strength and toughness of the headed assembly. A thinner head profile than that shown is not suggested.

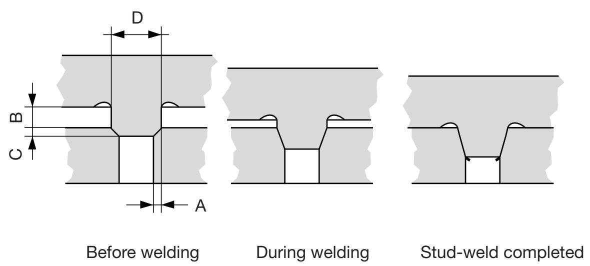
b) Stud Welding

Ultrasonic stud welding, a variation of the ‘‘shear joint’’ technique, can be used to join plastic parts at a single point or numerous locations.

In many applications requiring permanent assembly, a continuous weld is not required. Frequently, the size and complexity of the parts seriously limits attachment points or weld location. With dissimilar materials, this type of assembly is generally accomplished by either cold heading, ultrasonic heading or by the use of rivets or screws. When similar plastics are used, ultrasonic stud welding can perform the function with greater ease and economy. The power requirement is low, because of the small weld area, and the welding cycle is short, almost always less than half a second.

Among the many applications where ultrasonic stud welding might be used are clock frames, timers, electromechanical devices, electrical connectors and pump impellers.

Fig. 10.64 shows the basic stud weld joint before, during, and after welding. Welding occurs along the circumference of the stud. The strenght of the weld is a function of the stud diameter and the depht of the weld.
Maximum strength in tension is achieved when the depth of the weld equals half the diameter. In this case, the weld is stronger than the stud.



Dimension A	0,25 to 0,4 mm for D up to 13 mm
Dimension B	Depth of weld B = 0,5 D for maximum strength (stud to break before failure)
Dimension C	0,4 mm minimum lead-in.
Dimension D	Stud diameter.

Fig. 10.64 **Ultrasonic stud welding**

The radial interference, A, must be uniform and should generally be 0,25 to 0,4 mm for studs having a diameter of 13 mm or less. Tests show that greater interference does not increase joint strength but does increase weld time.

For example, studs with a diameter of 5 mm with 0,4 mm interference require four times the weld cycles of studs with 0,25 mm interference welded to the same depth. The hole should be at sufficient distance from the edge to prevent breakout.

In the joint, the recess can be on the end of the stud or in the mouth of the hole, as shown in several of the examples. When using the latter, a small chamfern can be used for rapid alignment.

To reduce stress concentration during welding and in use, an ample fillet radius should be incorporated at the base of the stud. Recessing the fillet below the surface serves as a flash trap which allows flush contact of the parts.

Other ways in which the stud weld can be used are illustrated in Fig. 10.65. A third piece of a dissimilar material can be locked in place as in view *A*. View *B* shows separate moulded rivets in lieu of metal self-tapping screws or rivets which, unlike metal fasteners, produce a relatively stress-free assembly.

Fig. 10.66A shows a variation which can be used where appearance is important or where an uninterrupted surface is required. The stud is welded into a boss. The outside diameter of the boss should be no less than 2-times the stud diameter. When welding into a blind hole, it may be necessary to provide an outlet for air. Two methods are possible, a center hole through the stud, or a small, narrow slot in the interior wall of the boss.

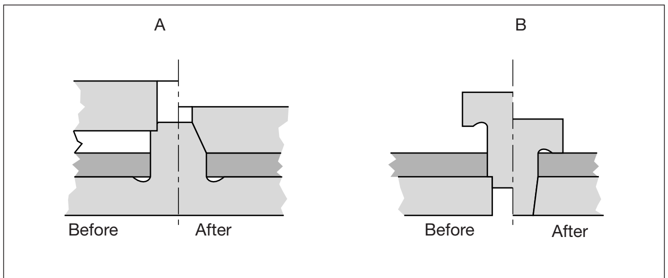


Fig. 10.65 **Stud welding – Variations**

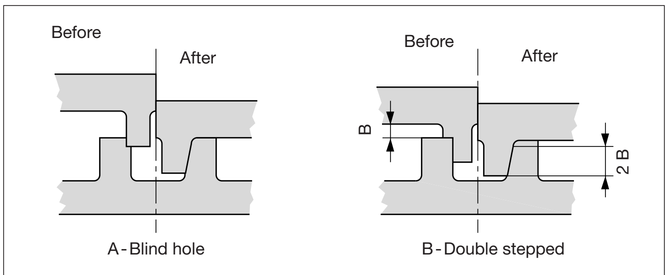


Fig. 10.66 **Stud welding – Variations**

When the amount of relative movement during welding between two parts being assembled is limited such as when locating gears or other internal components between the parts, a double stepped stud weld as in Fig. 10.66B should be considered. This reduces the movement by 50% while the area and strength of the weld remain the same.

This variation is also useful when welding plugs into thin walls (1,5 mm) as seen in Fig. 10.67. With the standard stud joint, the requirement lead-in reduces the available area and strength.

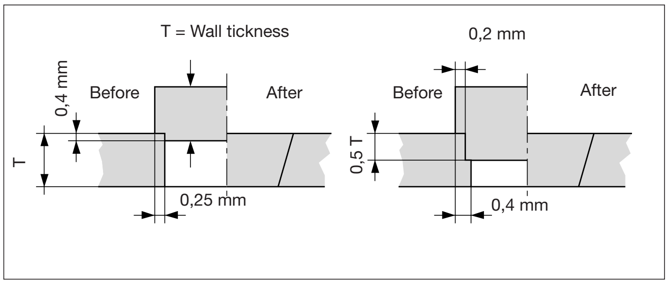


Fig. 10.67 **Stud welding – Plugs in thin-wall parts**

Standard horns with no special tip configuration (as needed for ultrasonic heading) are used. High amplitude horns or horn and booster combinations are generally required. Best results are obtained when the horn contacts the part directly over the stud and on the side closest to the joint. When welding a number of pins in a single part, one horn can often be used. If the studs are widely spaced (more than 75 mm between the largest distance of the studs) small individual horns energized simultaneously must generally be used. Several welding systems which can accomplish this are described earlier in the report.

c) Ultrasonic Inserting

Metal parts can be ultrasonically inserted into parts of DuPont engineering plastics as an alternative to moulded-in or pressed-in inserts. Several advantages over moulded-in inserts are:

Elimination of wear and change to moulds,

Elimination of preheating and hand-loading of inserts,

Reduced moulding cycle,

Less critical insert dimensional tolerances,

Greatly reduced boss stress.

The inserts can be ultrasonically inserted into a moulded part or the moulded part can be assembled over the insert as seen in Fig. 10.68. There are several varieties of ultrasonic inserts commercially available, all very similar in design principle. Pressure and ultrasonic vibration of the inserts melts the plastic at the metal-plastic interface and drives the insert into a moulded or drilled hole.

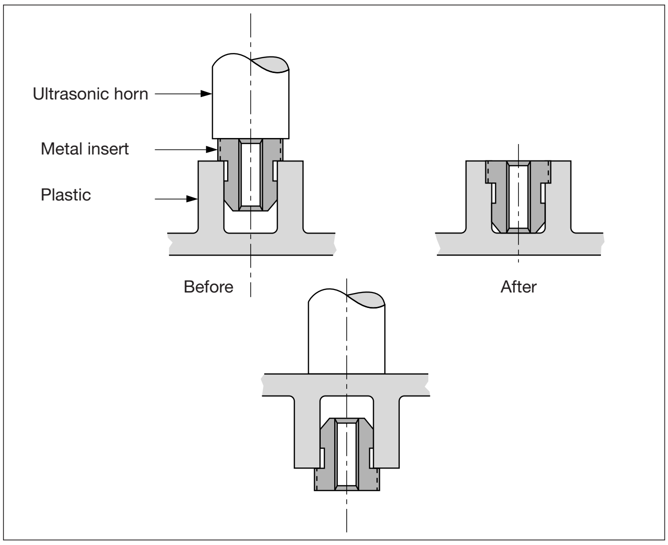


Fig. 10.68 **Ultrasonic inserting**

The plastic, melted and displaced by the large diameters of the inserts flows into one or more recesses, solidifies, and locks the insert in place. Flats, notches, or axial serrations are included in the inserts to prevent rotation due to applied torsional loads. The volume of the displaced material should be equal to or slightly more than the volume of free space corresponding to the groove and the serrations of the insert.

Safety

Ultrasonic welding can be a safe process. However, certain precautions should be taken to insure such safety.

a) Ultrasonic welding machines should be equipped with dual actuating switches, thereby insuring that the operators' hands remain clear of the welding horn. Stop or safety override switches should also be installed so that welding machines can be stopped at any time during its cycle or downward travel.

b) Vibration welding horns should not be squeezed or grabbed, nor should the unit be brought down by hand under pneumatic cylinder load. Light skin burns may result from the former, and severe burns as well as mechanical pinching will result from the latter.

c) Welding machines operate at 20 000 cycles per second, above normal audibility for most people. However, some people may be affected by this frequency of vibrations and by lower frequency vibrations generated in the stand and parts being welded.

An enclosure with absorption lining similar to that shown in Fig. 10.69, may be used to reduce the noise and other possible effects of the vibrations. The enclosure should be complete and not just a barrier. If this is not possible, ear protectors should be worn by all production line operators and by others working near the welding equipment.

Laboratory technicians working occasionally with ultrasonic welding machines should wear ear protection if sounds from the welding machine produce discomfort. Some welding horns, shaped very much like bells, may produce intense sound vibrations when improperly operated. These vibrations may cause nausea, dizziness, or potentially permanent ear damage.

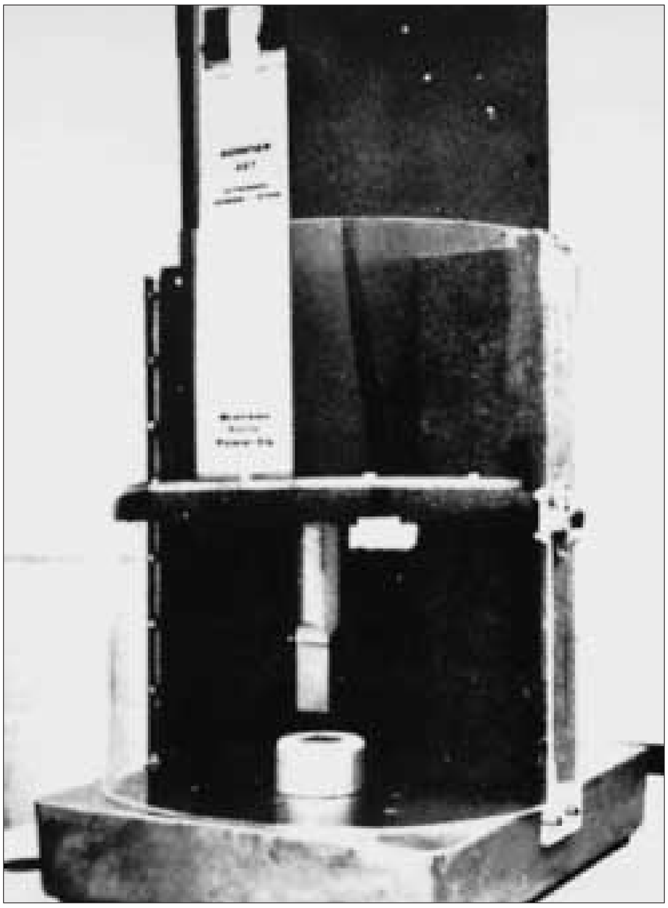


Fig. 10.69 **Noise shield**

Vibration Welding

Introduction

Vibration welding as such has been known for many years and applied in some special fields. The DuPont Company, however, has further developed and improved the technique to the extent at which it can be used in the broad field of engineering plastic materials. In addition, DuPont was the first to produce adequate prototypes of equipment to demonstrate the feasibility and usefulness of this method for joining industrial plastic parts.

Vibration welding is a simple technique and does not require sophisticated mechanical or electrical equipment. The welding cycle can be divided into the following steps:

1. The two parts are put into suitably shaped jigs on the machine.
2. The jigs move towards each other to bring the joint surfaces into contact under continuous pressure.
3. Vibrations, generated either by a gear box or by an electric magnet, are transmitted to the jigs and through them to the joint surfaces. The motions of the two parts take place in opposite directions, thus creating a relative velocity at the weld surfaces. As a result of friction, temperature rises immediately, reaching the melting point of the plastic, usually in less than a second.
4. After a pre-set time, an electrical control device stops the vibrations whilst pressure on the joint is maintained. Simultaneously the parts are brought into the correct position relative to each other.
5. Pressure is maintained for a few seconds to allow the melt to freeze. Then the jigs open and the welded parts are ejected.

Basic Principles

The various weld methods for joining parts in thermoplastic materials differ essentially in the way heat is built up on the joint surface.

The presently known procedures can be split into two basically different groups:

1. The heat required to reach the melting temperature is supplied by an outside source. This is the case with: hot plate welding, induction welding and hot air welding.
2. The necessary heat is generated directly on the joint surfaces by means of friction. The best known methods using this procedure are spinwelding and ultrasonic welding. They have the obvious advantage that the melted resin is never exposed to open air, in this way preventing decomposition or oxidation which, for some plastics, must be avoided.
   Spinwelding, however, is limited to circular shaped parts which, in addition, do not require positioning. If the two items are to be joined in an exact position relative to each other spinwelding equipment becomes quite costly because there are no simple mechanical means to fulfill this requirement.

Vibration welding belongs to the second group since it produces heat by means of friction on the two joint surfaces. Unlike the spinwelding procedure, vibration welding is not limited to circular parts. It can be applied to almost any shape provided that the parts are designed to permit free vibrations within a given amplitude.

Definition of Motion Centre

The centre around which two parts vibrate can be located:

a) inside the joint area;

b) outside the joint area;

c) at an infinite distance, in which case the motion becomes linear.

Based on this, two distinct variations can be defined: *Angular and linear welding.*

a) *Motion centre inside the joint area*
All parts having a perfectly circular weld joint would logically vibrate around their own centre as shown in Fig. 10.71A. Such parts can be provided with a V-shaped weld joint as described in chapter ‘‘Circular Parts’’. All parts having a non-circular shape must of course be provided with flat joint surfaces. If the weld area has an irregular shape, as for instance shown in Fig. 10.71B, it can still vibrate around an internal centre. The latter would, however, be choosen in a place which produces the least possible difference in circumferential velocity.
From experimentation it has been found that if the ratio of X / Y exceeds ~1,5, the motion centre must be placed outside the joint.

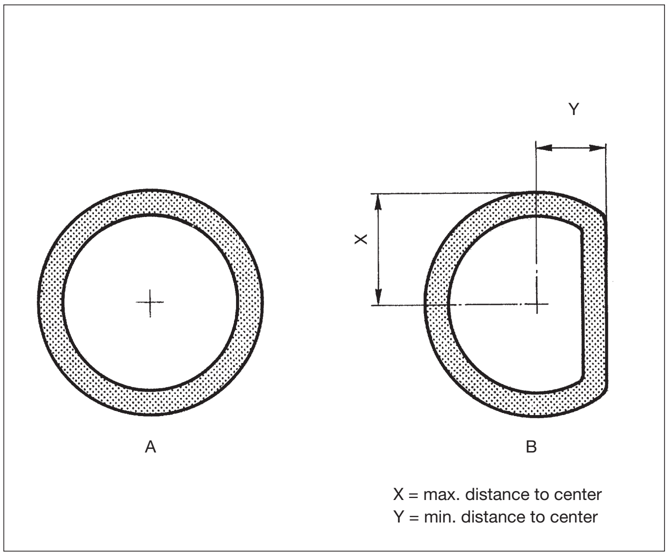


Fig. 10.71 **Weld Joint Shapes**

Parts having a rectangular weld area similar to that shown in Fig. 10.72A can also vibrate around their own centre provided the above mentioned ratio is not over ~1,5 to 1,0.

With a shape like that shown in Fig. 10.72B, the motion centre would have to be located externally in order to obtain similar weld velocities all over the joint.

b) *Motion centre outside the joint area*
In cases where the above described conditions are not fulfilled, parts must be placed far enough from the motion centre to obtain again a ratio of X / Y <1,5 as shown in Fig. 10.73A. This arrangement permits simultaneous welding of two or more parts. It is equally possible to weld simultaneously items having different sizes and shapes. They must, however, be arranged in the vibrating jig symmetrically in order to obtain the same surface pressure on all joints, as shown in Fig. 10.73B.

c) *Linear welding*
Parts which, for reasons of shape or size, do not fit into an angular jig may be welded by means of linear vibrations. This method is especially appropriate for large size non-circular parts above a length of 100-150 mm. It is, however, also possible to weld several parts simultaneously provided they can be fitted into the vibrating plates.

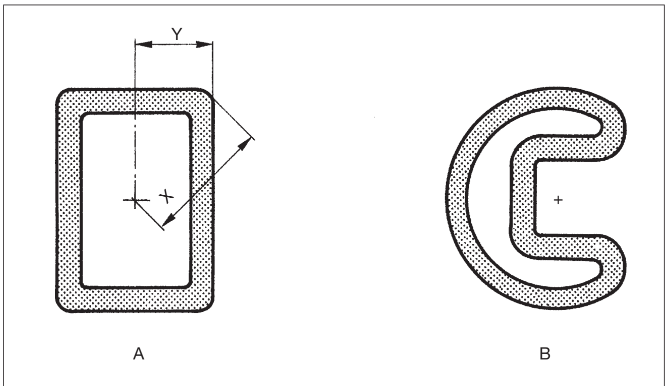


Fig. 10.72 **Location of Motion Centre**

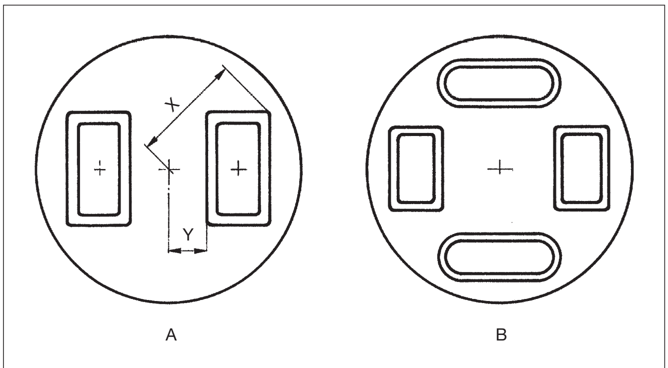


Fig. 10.73 **Simultaneous Welding of Multiple parts**

Typical Arrangements for Producing Vibrations

Although vibrations can be generated by means of alternating current magnets, all available machines so far have been equipped with mechanical vibration generators.

Fig. 10.74 shows schematically the function of a linear welding machine as was first perfected by DuPont. The vibrations are generated by two eccentrics *a* rotating around centre *b* and transmitted to jigs *c* by rods *d*. The lower jig slides in two ball bearing rails allowing free lengthwise motion. The upper jig is pressed down by four pneumatic operated levers *e*.

It is essential to synchronize mechanically the motions of the latter in order to obtain a perfect parallelism of the parts to be welded.

At the end of the weld cycle, motion transmission is disengaged whereupon both parts are brought into the final position and pressure is maintained for a short time to allow freezing of the melted resin.

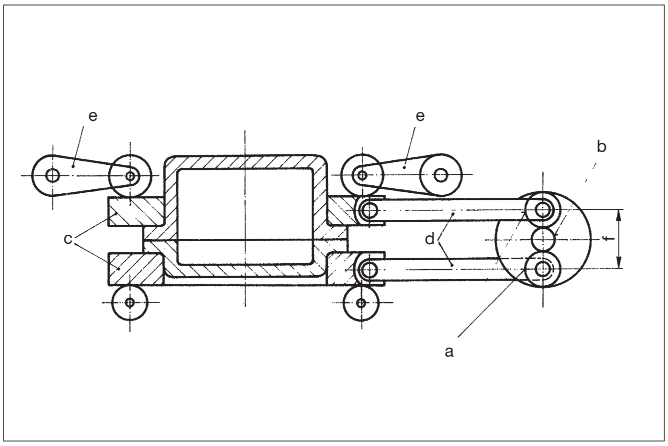


Fig. 10.74 **Principle of Linear Welding Machine**

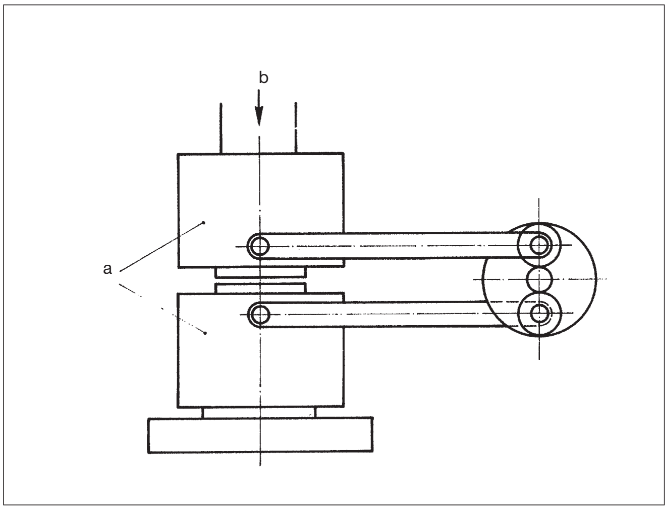


Fig. 10.75 **Principle of Angular Welding Machine**

The same basic device is used for an angular welding machine as indicated in Fig. 10.75. In this case, vibrations are transmitted to the upper and lower jigs *a* rotating on ball bearings. The upper jig is mounted directly onto the piston rod *b* to provide pressure.

Theoretically, the same weld result could be obtained with one part stationary and the other vibrating at twice the frequency. Experience has proven, however, that this method is unsatisfactory for various reasons. As illustrated in Fig. 10.74 and 10.75, the considerable acceleration and deceleration forces cancel out, provided that the weight of the upper jig plus the plastic part is equal to the weight of the lower jig plus the plastic part. (In the case of angular welding the two moments of inertia must be identical to provide equal and opposite inertia forces.)

If one part is only vibrated at twice the frequency, the acceleration and deceleration forces are four times higher and would have to be compensated for by means of an additional and adjustable device. The whole gear box would therefore be much heavier and more expensive for a machine having the same capacity. In addition, it has been shown empirically that it is easier to obtain a good, tight joint if both parts are vibrating.

Welding Conditions

In order to reach the melting point of the material, two parts must be pressed together and vibrated at a certain frequency and amplitude. These conditions can be defined as a PV value, where P is the specific joint pressure in MPa and V the surface velocity in m/s.

The two eccentrics generate a sinusoidal velocity curve as shown in Fig. 10.76. Since they move in opposite directions, the maximum relative velocity of one part against the other is 2 W. The resulting relative velocity is therefore 1,27 times the maximum value W.

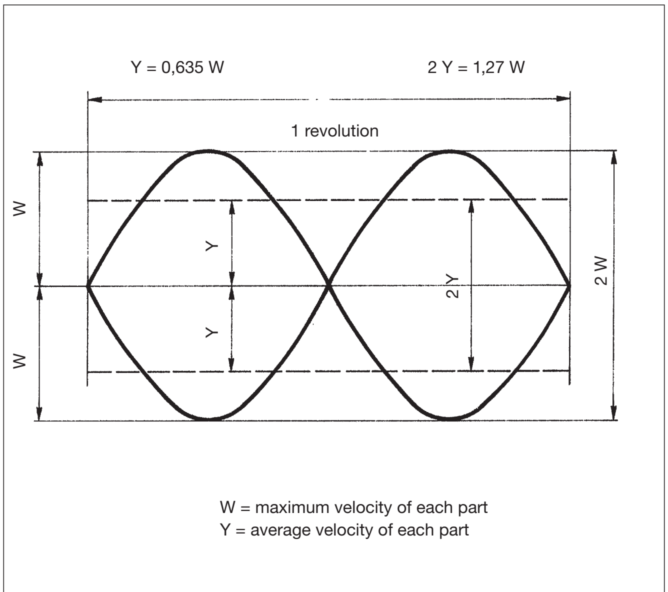


Fig. 10.76

Example: A machine welding acetal according to Fig. 10.74 has an eccentric distance *f* of 3 mm and runs at a speed of 5000 rpm. The circumferential velocity is therefore:

$$V = f \times \pi \times n = \frac{0{,}003 \text{ m} \times \pi \times 5000}{60} = \mathit{0{,}78\ m/s}$$

This equals the maximum velocity W in Fig. 10.76. The average relative velocity of one part against the other would then be:

$1{,}27 \times 0{,}78 =$ *1 m/s*

At a specific joint pressure of 3 MPa, the resulting PV value becomes:

$3 \times 1 =$ *3 MPa × m/s*

As the generated heat is also a function of the coefficient of friction, the above PV value must be related to the materials being welded. Glass reinforced polyamide for instance has been welded successfully at a PV value of 1,3. It would therefore appear that a machine which is sup-posed to weld various materials and part sizes should be provided with adjustable pressure, speed and amplitude. Once the best working conditions are determined for a given part, the production machine would, however, not require any adjustments, except for the pressure.

Weld time is a product of velocity, pressure and amplitude. Experience has shown, however, that above a certain pressure, joint strength tends to decrease, possibly due to squeezing out of the molten resin. On the other hand, there are certain limits with regard to the resulting mechanical load on the gear box. Thus, doubling the speed produces four times higher acceleration forces of the vibrating masses.

Extensive tests have proven that a frequency of about 100 Hz is very convenient for small and medium size parts whereas larger, heavy parts are welded at a frequency of 70-80 Hz.

However, successful joints for big parts have also been designed, using frequencies up to 250 Hz, see also Fig. 10.79 D.

On linear machines, the distance of the two eccentrics (*f* in Fig. 10.74) should be adjusted in order to obtain a relative motion of about 0,9 × joint width, as shown in Fig. 10.77.

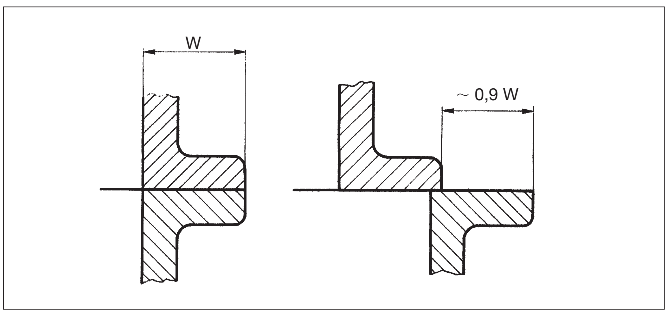


Fig. 10.77 **Relative Motion – Joint width**

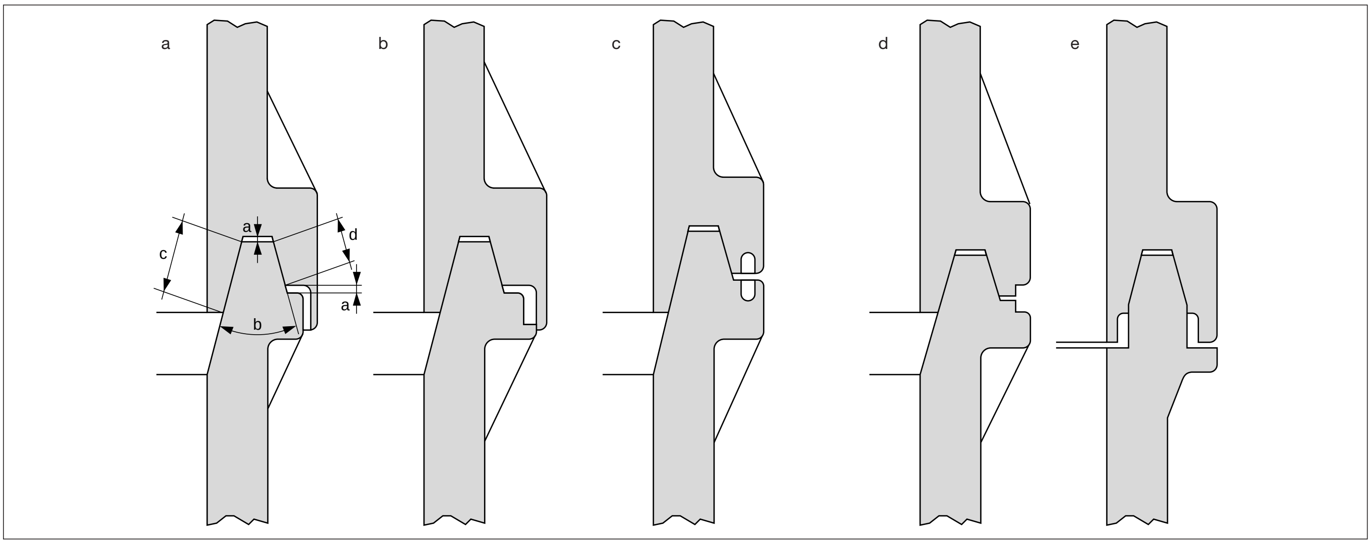


Fig. 10.78 **Joint Design – Circular Parts**

The specific surface pressure giving the highest joint strength must be determined by testing. As a basic rule it can be said that a machine should be capable of producing appr. 4 MPa of pressure on the surface to be welded.

Joint Design

a) Circular parts

Circular parts should always be provided with a V-shaped joint as used for spinwelding. Not only does such a design permit perfect alignment of the two halves but the welded surface can be increased, thus reaching the strength of the wall section. During welding operations a certain amount of flash builds up on both sides of the joint. For certain applications this must be avoided either for aesthetic reasons or because it may be a source of trouble for internal mechanical parts. In such cases, joints should be provided with flash traps.

In order to transmit vibrations to the joint area, with the least possible loss, the plastic part must be held firmly in the jig. It is often advisable to provide the joint with 6 or 8 driving ribs, especially for thin wall vessels in soft materials.

A typical joint design with an external flash trap and driving ribs directly located on the shoulder is shown in Fig. 10.78a. There are a few basic requirements to be kept in mind:

- Before welding, the flat areas should be separated by gap *c*, which is appr. 0,1× the wall thickness.
- The angle *b* should not be less than 30° in order to avoid a self locking effect.
- The welded length *c* + *d* must be at least 2,5× the wall thickness, depending on the desired strength. As some plastics are more difficult to weld than others, this value should be increased accordingly.

Fig. 10.78b and 10.78c show other possible arrangements for external flash traps.

On parts for which an aesthetic appearance is not essential a simple groove like that in Fig. 10.78d is often sufficient. It does not cover the flash but keeps it within the external diameter.

If both internal and external flash traps are required they can be designed for as shown in Fig. 10.78e.

b) Non circular parts

Non circular parts, whether they are welded on angular or linear machines can be provided with flat joints as shown in Fig. 10.79A. The joint width *W* should be at least twice the wall thickness, depending again on strength requirements and the plastic used. Strength does not increase significantly above a ratio W/T = 2,5–3,0, due to unequal stress distribution (see also Fig. 10.81).

Square and rectangular shaped parts, especially with thin walls or moulded in soft plastics are not stiff enough to transmit vibrations without loss. They must therefore have a joint as shown in Fig. 10.79B with a groove around the whole circumference. This groove fits onto a bead on the jig *a* to prevent the walls from collapsing inwards. It is most important to support the joint on both surfaces *b* and *c* to achieve perfect weld pressure distribution.

A possible way of adapting flash traps on butt joints is shown in Fig. 10.79C. Gap *a* must be adjusted to obtain a complete closure of the two outer lips after welding. This design reduces the effective weld surface and may need wider joints for a given strength.

Another joint design, with flash trap, is shown in Fig. 10.79D. This joint has been used successfully in vibration welding of covers for air-intake manifolds at frequencies of up to 250 Hz, with amplitudes of 1,2 mm.

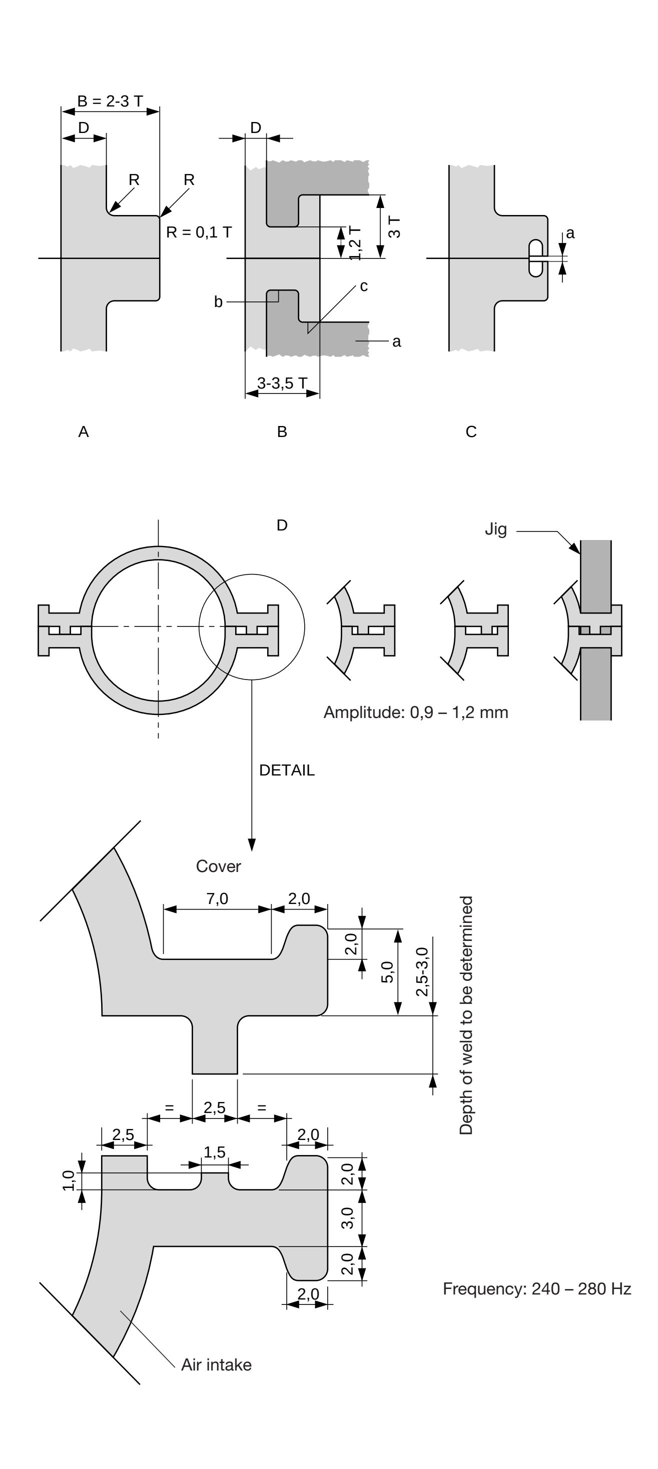


Fig. 10.79 **Joint Design – Non Circular Parts**

Test Results on Angular Welded Butt Joints

The rectangular box shown in Fig. 10.80 was used for extensive pressure tests in various DuPont materials. The burst pressure of any vessel is influenced by three main factors:

- overall design
- material weldability
- joint design.

The results obtained and described below should therefore be applied carefully to parts having different shapes and functions. The same part moulded in different plastics will show quite different behaviour. Whereas in some cases the weld may be the weakest spot, in other engineering plastic resins it may prove to be stronger than the part itself.

Joint Strength versus Welded Surface

Fig. 10.81 shows the tensile strength as a function of joint width, obtained on the vessel shown in Fig. 10.80. A linear strength increase can be observed up to a ratio W/T of appr. 2,5. Above this value the curve tends to flatten out and increasing the width does not further improve strength.

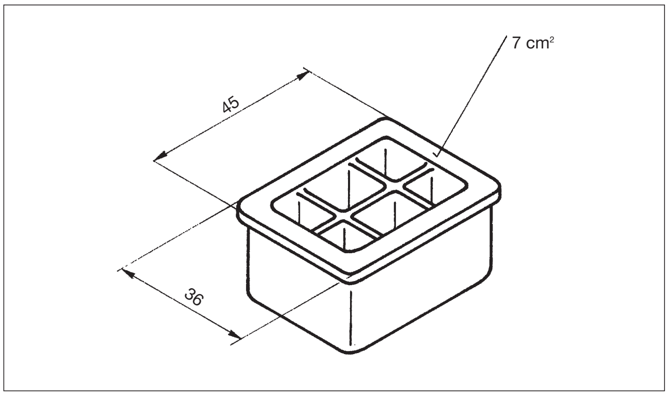


Fig. 10.80 **Burst Pressure Test Piece**

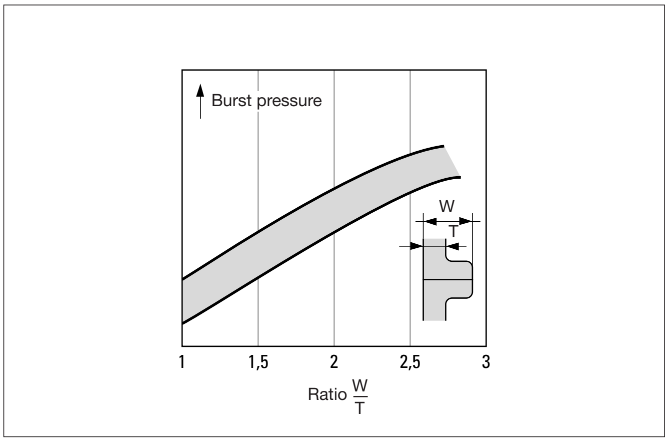


Fig. 10.81 **Joint Strength versus Joint Size**

Joint Strength versus Specific Weld Pressure

As already mentioned, the appropriate specific weld pressure should be determined for each plastic material by trials. For DELRIN® 500 for instance, it was found to be about 3,3 MPa as plotted on the curve in Fig. 10.82. It appears that too high a pressure reduces joint strength as well as too low a pressure.

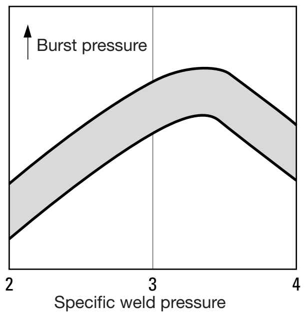


Fig. 10.82 **Specific Weld Pressure Influences Joint Strength**

All grades of DELRIN® are suitable for vibration welding. DELRIN® 500F gives the best results, whereas DELRIN® 100 is somewhat inferior. Weld joints on parts in DELRIN® 100 are usually the weakest area due to the high elongation of this resin. This was also the case for the test vessel shown in Fig. 10.80. The same part moulded in DELRIN® glass filled resin does not break at the joint but in a corner, because of the lower elongation. It must also be kept in mind that coloured compositions have a lower weld strength than the same grade in natural colour. This applies to all polymers. Pigment loadings have a slight adverse effect on properties. Even though the average strength values differ somewhat from one grade to another, it is surprising to notice that the upper limit of about 14 MPa tensile strength is the same for most grades.

Vibration welding is equally suitable for all grades of ZYTEL® nylon resins. It allows many new and attractive applications for which no other weld procedure would be applicable. The automotive industry in particular requires various non-circular vessels and containers in the cooling circuit as well as for emission control filters.

No special care has to be taken concerning water absorption before welding, provided that the parts are stored at a relative humidity no higher than 50%.

Butt joints of parts in unreinforced polyamide are usually stronger than the part itself. Fillers and glass fibres reduce joint strength depending on their quality. Thus 30% glass fibres cause a reduction of up to 50% in strength. Parts in this resin must be designed very carefully.

Design Examples

Fig. 10.83. A typical centrifugal pump design with an angular welded spiral housing in DELRIN®.

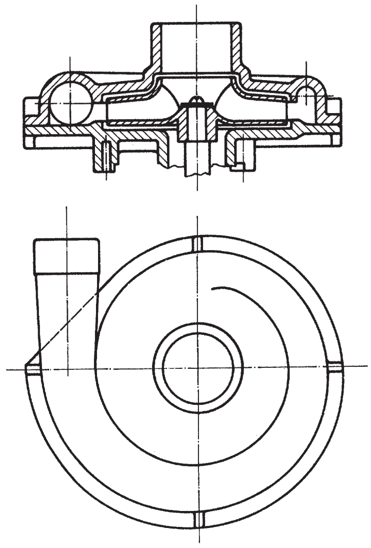


Fig. 10.83 **Centrifugal pump**

Fig. 10.84. An automotive tank in ZYTEL® nylon 66 resin. The joint is provided with a flash trap to avoid any post deflashing operation.

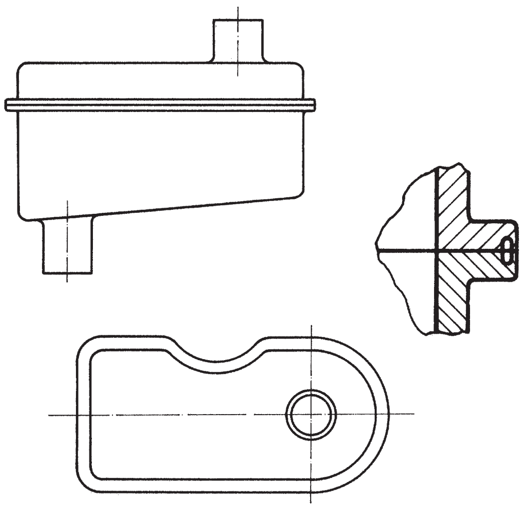


Fig. 10.84 **Automotive tank**

Fig. 10.85. A linear welded motor bicycle petrol tank in ZYTEL®. The groove in the joint collects flash, then a PVC profile is snapped over the flange. This is one solution which effectively hides the whole weld joint.

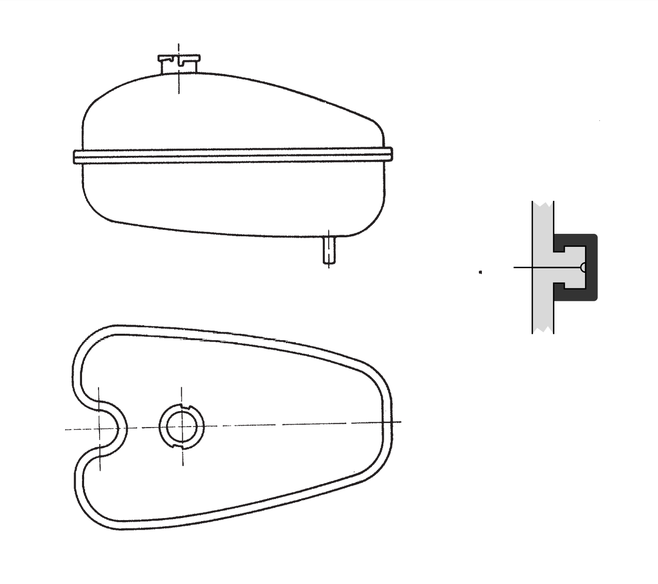


Fig. 10.85 **Motor bicycle petrol tank**

Fig. 10.86a. An angular welded, square shaped gasoline filter housing in ZYTEL®. The joint is provided with a groove to retain the thin walls in the jigs, thus preventing them from collapsing during the welding operation.

Fig. 10.86b. An angular welded container in ZYTEL®. Body and cover house connections must be oriented in the given position. A classic spinweld joint with an external flash trap is used for this vibration welding technique.

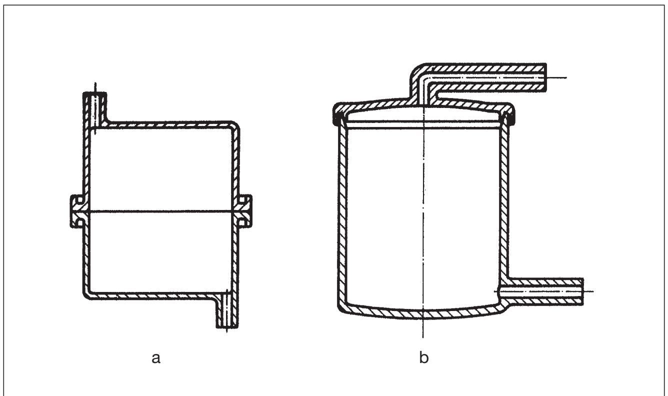


Fig. 10.86 **Angular Welded Parts**

Fig. 10.87. Rubber diaphragm assemblies can also be welded by angular vibrations. Steps must be taken, however, to prevent the upper part from transmitting vibrations directly to the rubber. This can be achieved by means of a very thin nylon washer onto the diaphragm, the use of graphite powder or a drop of oil. The solenoid valve in ZYTEL® glass fibre reinforced nylon resin shown here has a burst pressure of 8-9 MPa. A significant advantage over self tapping screw assemblies lies in the fact that a welded body remains tight up to the burst pressure.

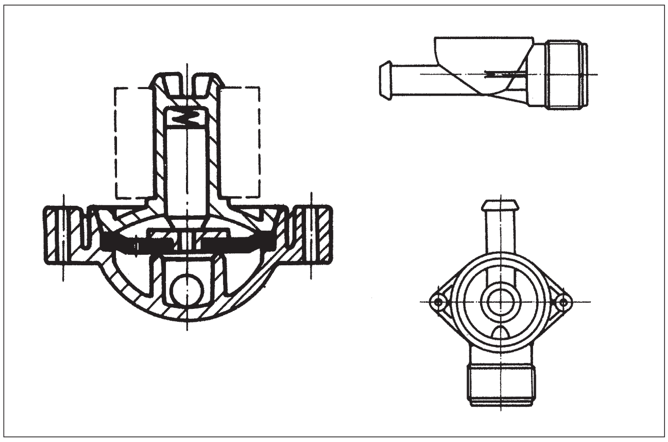


Fig. 10.87 **Housing for diaphragm**

Comparison with other Welding Techniques

Vibration welding is by no means a rival to ultrasonic welding although in some cases they may compete. The solenoid valve shown in Fig. 10.87 can for instance easily be welded ultrasonically. However, the high frequency can cause the thin metal spring to break, in which case the whole housing must be scrapped. Sometimes a complicated part shape does not allow the welding horn to come close enough to the joint. In addition gas and air tight ultrasonic joints require close tolerances which cannot always be achieved.

Thin wall vessels such as pocket lighters can never be provided with a large enough joint to reach the required burst pressure. It would therefore be unwise to weld them on a vibration machine. Here ultrasonic welding is the preferred technique.

Vibration welding can be considered in many applications as a rival to hot plate welding against which it offers some considerable advantages:

– much shorter overall cycle;
– lower sensitivity to warpage, as the relatively high weld pressure flattens the parts out;
– since the molten resin is not exposed to air, the procedure is also suitable for all polyamide grades.

Vibration welding is not a competitor to pure spinwelding. For all circular parts which do not require a determined position to each other, spinwelding is still the cheapest and fastest assembly technique.

Design Considerations for Vibration Welded Parts

Parts which are intended to be assembled by vibration welding must be designed correctly to avoid rejects and failures. Perfect fitting of the joint area is essential.

The first step is to choose an adequate joint giving the required strength and tightness. It should be decided at this stage of development whether flash traps or means to cover or conceal the joint are necessary.

It is essential to support the joint flange all around the part in order to maintain equal pressure over the whole weld area.

If, as shown in Fig. 10.88, the jig cannot fulfill this requirement due to an interruption, weak spots or leakage can be expected.

Thin ribs, however, are permissible, provided their thickness does not exceed appr. 80% of the wall section (Fig. 10.89).

Special care must be taken to make sure vibrations are transmitted from the jig to the part with as little power loss as possible. Such loss may occur from too much clearance in the jig or because the part is held too far away from the joint.

Circular parts without protruding features allowing a tight grip must be provided with ribs as shown in Fig. 10.78a.

With parts having relatively thin walls or which are moulded in soft materials, vibrations should be transmitted to the part as near to the joint area as possible. For non-circular parts this is often only possible with a design similar to that shown in Fig. 10.79b, regardless of whether it is a linear or angular weld.

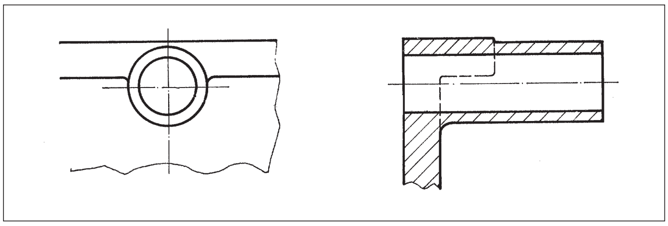


Fig. 10.88 **Bad joint design**

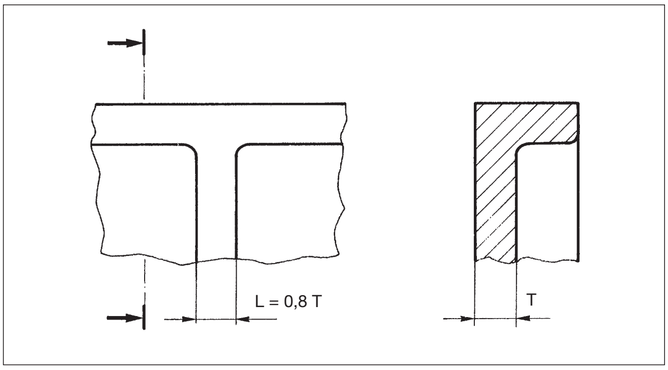


Fig. 10.89 **Ribs in Vibration Welded Parts**

Some materials which have a high coefficient of friction, as for instance elastomers, require an initial surface lubrification before they can be satisfactorily vibrated and welded.

The amount of melt produced during the vibration cycle is in direct relation to the surface flatness. Stiff parts, especially in glass filled resins, may not be flattened out completely by the weld pressure and so require longer vibration cycles to achieve good joints. When designing and moulding such parts, it should therefore be kept in mind that the total assembly time depends partially on joint levelness which in turn can often be improved with appropriate design.

Fig. 10.90a **Vibration welding machine.**

Fig. 10.90b **Commercial linear and angular welding machine. Manufacturer: Mecasonic SA, Zone industrielle, Rue de Foran, Ville-la-Grand, Case postale 218, 74104 Annemasse Cédex, France.**

Fig. 10.90c **Commercial linear welding machine.**

Hot Plate Welding

Introduction

Hot plate welding is a technique used for joining thermoplastic parts. Non symmetric parts with fragile internal components which can not accept vibration or ultrasonic welding are suitable for this technique.

The joining of thermoplastic materials is obtained by fusion of the parts surfaces through bringing them into contact with a TEFLON® PTFE coated electrically heated plate. The parts are then pressed together. Alternatively heat can be radiated onto the welding surface using specially designed equipment.

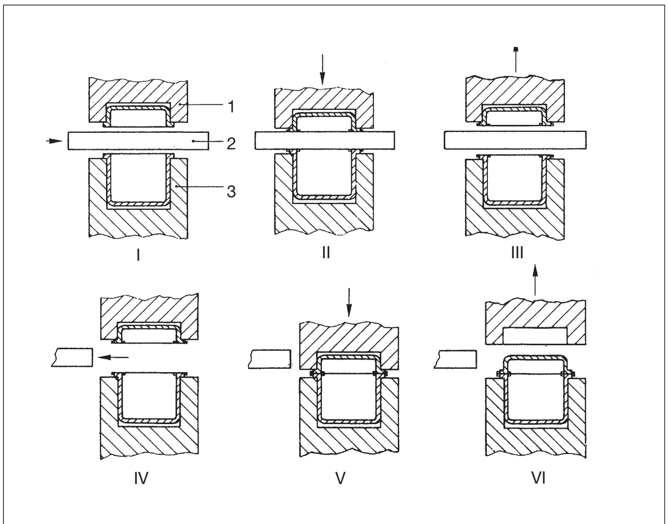


Fig. 10.91 **Hot Plate Welding Cycle**

Welding Cycle

Fig. 10.91 shows step by step (I to VI) the typical hot plate welding cycle using an electrically heated, TEFLON® PTFE coated plate to melt the welding surfaces.

Joint Design

The joint width *W* should be at least 2,5 times the wall thickness for engineering materials (Fig. 10.92a).

Fig. 10.92b-c show possible ways of incorporating flash traps. Gap *a* must be adjusted to obtain a complete closure of the outer lips after welding. This design reduces the effective weld surface and may need wider joints to obtain the same strength as a conventional joint.

Thin walled parts may require a guiding jig. e.g. *a* shown in Fig. 10.92d to ensure adequate contact along the whole surface of the joint.

Note also in this example the larger ribbed joint (in comparison to the wall section) as well as the good support given by the jig at points *b* and *c* to achieve good weld pressure distribution.

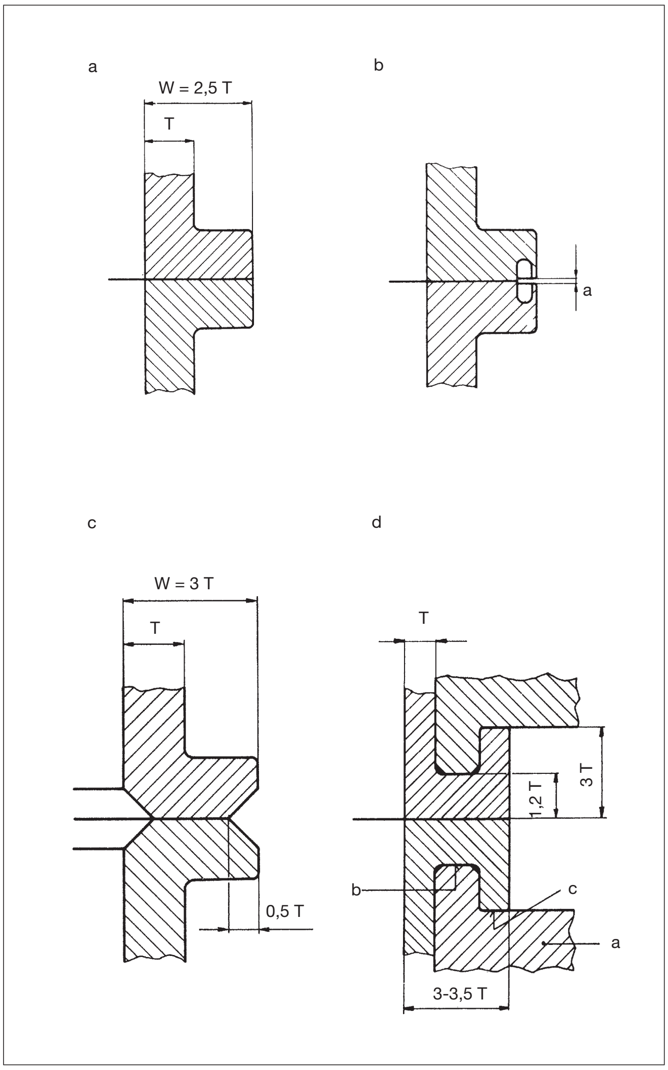


Fig. 10.92 **Joint Design for Hot Plate Welding**

Part Design for Hot Plate Welding

Parts must be designed correctly to avoid rejects and failures. The flatness of the joint area is essential and therefore the design laws for engineering materials should be strictly applied. In particular even wall sections, suitably designed with radiused corners everywhere are vital.

Limitations of Hot Plate Welding

– Polyamide based resins are in general unsuitable for hot plate welding since they oxidise when the melted resin is exposed to air during the welding cycle. The oxidised material will not weld properly.
– Relative to other plastics welding techniques, cycles are long (in the range 30–45 s).
– Some sticking problems between the polymer and the hot plate are possible. TEFLON® PTFE coating of the plate tends to reduce this considerably.
– Only similar materials can be joined by this method.

Practical Examples

Practical applications of Hot plate welding are shown in Fig. 10.93.

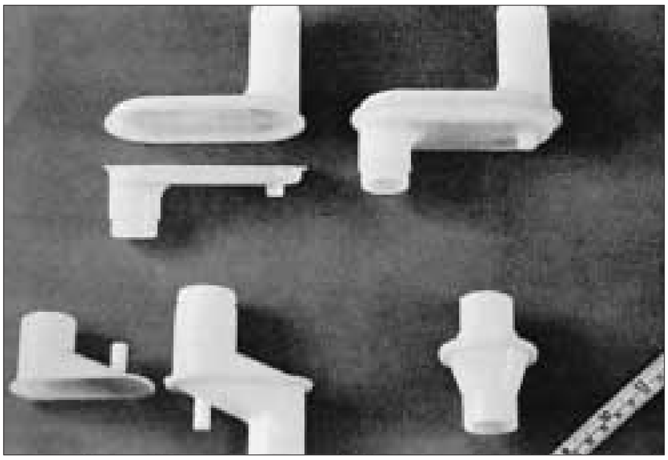
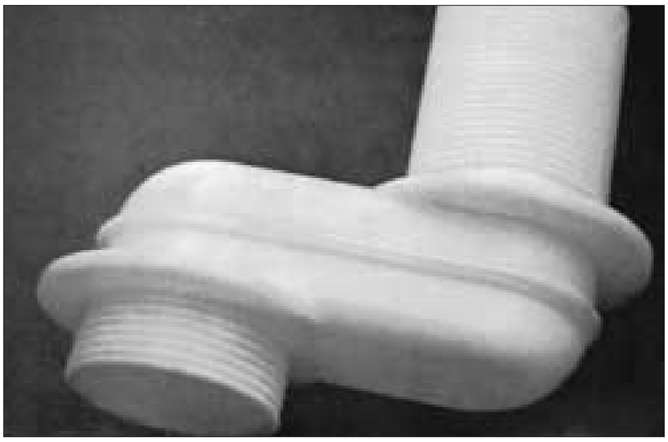


Fig. 10.93 **Applications of Hot Plate Welding**
a – Gas meter parts



b – Drain part

c – Lighter

Hot Plate Welding of ZYTEL®

One of the main problems in welding ZYTEL® nylon 66 is oxidisation and speed of crystallization. Unlike the shear joint as used in Ultrasonic welding or the joint used in Vibration welding, the surface of the joint is exposed to cold air when the hot plate is removed to allow the two parts ot come together. During this time the plastic will tend to oxidise and result in a poor weld.

But with care and attention to certain parameters, ZYTEL® can be hot plate welded to give a weld of good strength in relation to the parent material strength.

The ZYTEL® must be dry as moulded. Welding immediately after moulding is the ideal case, although a delay of 48 hours is acceptable. If this is not practical the parts must be dried to a moisture content below 0,2%. The effect of moisture on the weld quality is quite dramatic. A frothy weld flash will be observed indicating a "wet" material, moisture will promote oxidisation and porosity in the weld and thus reduces the strength of the weld by up to 50%.

Fillers in the plastic will also effect the weld strength. The strongest joint will be achieved with the natural unreinforced Nylon. Glass fibres will obviously not weld to each other and will not move across the weld joint, this gives a similar weakness as a weld line in a moulded part, up to 50% reduction in strength. The strength of the joint is inversely proportional to the glass content.
More glass = lower strength. Carbon black will also adversely affect the weld quality.

Hot plate temperature. Normally as a general rule the temperature of the plate is set to +20° C above the melt temperature of the plastic to be welded.

In the case of ZYTEL® nylon 66 with a melt temperature of 262° C, the plate temperature would be around 285° C. Attention must now be paid to the TEFLON® or PTFE coating on the plates to avoid sticking, because at this temperature the TEFLON® coating will start to fume off.

At a temperature of 270–275° C, the TEFLON® will begin to fume off and the PTFE tape to visibly bubble. To avoid this problem the temperature of the plate should be 265–270° C. This is below the + 20° C rule so a longer heat soak time should be used to compensate for the lower temperature. Another problem with welding at elevated temperatures is that at around 275° C the aluminium plate will warp. To over come this problem Aluminium Bronze plates should be used, these can go up to 500° C.

The jigging of the tow components is quite important. If the jig is made from metal and comes quite high up the part close to the weld line, it will act as a large heat sink, taking away the heat built up in the part durring the heat soak phase. Fast cooling of the parts result in a fast rate of crystallization not allowing the plastic to weld efficiently. Slow cooling is prefered. Non metallic jigs are a solution.

Other parameters

Heat soak time, is part and joint dependant, normally in the area of 15 s / min.

Cooling / hold time, similar to heat soak time.

Pressures during weld phase from 0,5 to 2 MPa = 5 to 20 bar.

Joint design, the general rule for the joint dimension is 2,5 × thickness. Tests have shown that if the general wall thickness is 2 mm the weld joint should be 5 mm thick, in order to give a joint strength comparable with the wall strength. Depending on the conditions in service of the part, maximum strength may not be required. For example a small breather pipe would not need such a high weld strength as a mounting bracket. So a thinner weld joint can be used, 1,5 to 2 × t. With less surface area to heat soak the cycle times will be quicker.

Fig. 10.94 **Hot plate welding machine.**

Transmission Laser Welding

Two parts, of which one must be made out of a transparent material, are welded together using laser light for melting both materials at the interface.

The word "LASER" is an acronym and stands for:

Light **A**mplification by the **S**timulated **E**mission of **R**adiation

The laser concept was first introduced by Al Einstein in 1917, but only in 1960 Edward Teller produced the first working laser. In just 40 years lasers have become an accepted part of our lives, from printers, CD players, bar-code scanners to medical surgery and communication devices.

A laser is a device that creates and amplifies a narrow, intense beam of coherent light. Atoms emit radiation, normally, they radiate their light in random directions at random times. The result is incoherent light – a technical term for what can be considered as a jumble of photons going in all directions. The trick in generating coherent light is to find the right atoms with the right internal storage mechanisms and create an environment in which they can all co-operate, to give up their light at the right time and all in the same direction.

In Ed Teller's laser the atoms or molecules of a ruby are excited in what is called the *laser cavity*. Reflective surfaces, mirrors, at both ends of the cavity permit energy to reflect back and forth, building up in each passage until at a certain point the process produces a sudden burst of coherent radiation as all the atoms discharge in a rapid chain reaction = the laser beam.

Atoms from different materials create laser beams of differing wavelength. Light wavelengths are very small in size and usually measured in nanometers, consider that 1 nm = 0,000001mm.

Visible radiation (light) which can be detected by the human eye has a wavelength in the range of 400 nm to 780 nm.

Different types of lasers

Some of the most common lasers are listed below:

CO_2	Carbon Dioxide molecule, emitting infrared energy.
Nd:YAG	Neodymium:Yttrium Aluminium Garnet synthetic crystal.
Diode	Semiconductor.
Excimer	A gas mixture, emitting ultraviolet light.

Table 10.01 **Different types of lasers**

		CO_2	Nd:YAG	Diode	Excimer
Wavelength	nm	10,600	1,060	800-1,000	150-350
Power	KW	45	4	4	1
Efficiency	%	10	3	30	1
Approx. cost	$	30,000*	60,000*	15,000*	120,000*

(*per 100 W)

In industry lasers have been active for some time cutting materials, it was concluded that if a laser could melt away steel at very high temperatures then powered down it could also cut polymer without vaporising the whole sample. It was then discovered that some polymers appear transparent to the wavelength of a laser while others absorbed the energy - creating heat.

With this concept in mind the process of Transmission Laser Welding was developed.

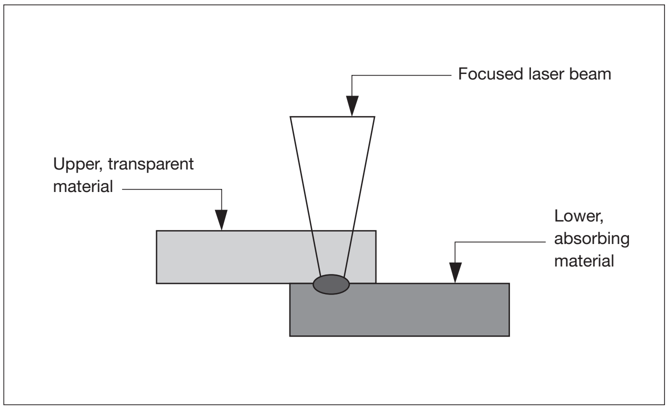


Fig. 10.95a **Transmission Laser Welding Concept**

The laser passes through the upper material without losing energy or damaging the polymer, the beam is then absorbed by the lower material causing rapid heating. This thermal effect melts the lower material that in turn heats the upper material resulting in a weld. Table 10.01 shows why the Diode laser is becoming an industry favourite for this welding technique due to its high efficiency compared to other laser types.

Advantages of TLW

- High weld speeds, 15 m / min demonstrated.
- Laser costs now compete with other assembly processes.
- Low laser power required, <50 W for typical thin wall parts.
- Easy manipulation for complex parts – robotically move the laser head.
- No visible marking or damage to the outside of the joint.
- No vibrational damage to the inside of the component.
- Precise controllable process, weld position and temp.
- Small focused amount of heat used, low thermal damage and distortion.
- No weld *flash* produced, very shallow *melt down*.
- Now possible to weld any colour to any colour, i.e. clear to clear.
- Different materials can be joined. – i.e. HYTREL® to CRASTIN®.
- Clamping can be achieved with transparent clamps.

Limitations

– Requires materials with different absorption characteristics for the laser.
– Intimate contact required at the joint, no part warpage, very little *gap* filling capability.
– Joint design limitations, joint must be *seen* by the laser.
– Material fillers can be troublesome, i.e. mineral, glass, carbon black.

Material Characteristics Required for TLW

The upper *transparent* material must have good transparency for effective welding. The inclusion of glass, fillers, etc. act as small reflectors scattering the laser beam as it passes through, thus reducing power at the interface. Most DuPont 'NC' grades have sufficient transparency for laser welding, with a few exceptions, i.e. ZENITE®.

The lower *absorbing* material must absorb the laser power, but not too quickly. The easiest additive to get absorption is Carbon Black, therefor nearly all our black polymers will absorb the laser energy. If the material contains too much carbon black then the material will tend to burn quickly before a good melt zone can be achieved. Too little carbon black will cause the laser beam to continue to pass through the material without generating sufficient heat to cause melt at the interface. A careful balance is needed.

Material Colours

Initial tests were conducted using NC coloured polymers on top of a carbon black coloured polymer. In certain applications this black and white appearance is acceptable, in other segments a need for a total black assembly is required – especially in automotive applications.

This can be achieved by using special pigments that cause the transparency of the upper part to be the same as in its NC state when viewed by the laser, but when viewed by the human eye the material absorbs the light and appears black in colour.

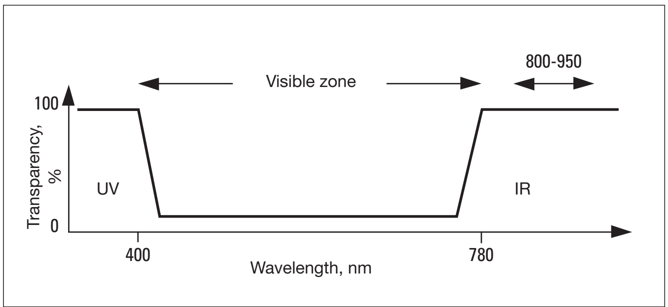


Fig. 10.95b **Wavelength zone for a *black* material to be transparent**

DuPont Material Properties

Table 10.02 shows a range of DuPont 'NC' polymers, these values help determine if a polymer is laser weldable or not.

Table 10.02 **Near infra-red analysis at 940 nm wavelength**

	% transmission	% reflection	% absorption
DELRIN® 500P	45,14	47,81	7,05
HYTREL® G4774	29,96	52,14	17,9
HYTREL® G5544	27,74	56,55	15,71
HYTREL® 4078W	34,7	42,8	22,5
HYTREL® 4556	33,32	45,53	21,15
HYTREL® 5556	28,38	53,92	17,7
RYNITE® 530	5	42	53
RYNITE® FR515	5,9	64,43	29,67
CRASTIN® SK605	8	59	33
ZYTEL® 101	80,61	9,64	9,75
ZYTEL® 73G30	48,28	12,72	39
ZYTEL® 70G33	36,8	23,68	39,52
ZYTEL® HTN51G35	19,15	29,48	51,37
ZENITE® 6330	0,65	76	23,35
ZENITE® 7130	0,13	69	30,87

It can be seen that ZENITE® reflects most of the laser power and thus can not be welded. RYNITE® also has low transparency needing high laser powers to achieve a weld.

Weld Strength

Weld strengths can be measured in a variety of ways. It is often quoted in 'Mpa' from a tensile test, this unit can then be compared to ISO data on unwelded test bars and is independent of weld size. This can then be translated to a *weld factor* which is the weld strength (MPa) divided by the strength of the parent material. Therefor if a weld factor is 1, it means the weld strength is the same as the parent material strength, this is an effective method of comparing materials which have the same joint size.

With Laser welding the joint size can be easily changed by adjusting the weld zone, which is simply done by moving the laser closer or farther away from the weld joint. The ultimate strength (measured in N force) of the weld can then be increased for a given material type.

With good joint design and process parameters a failure can often be achieved in the parent material way from the joint.

Typical Joint Designs

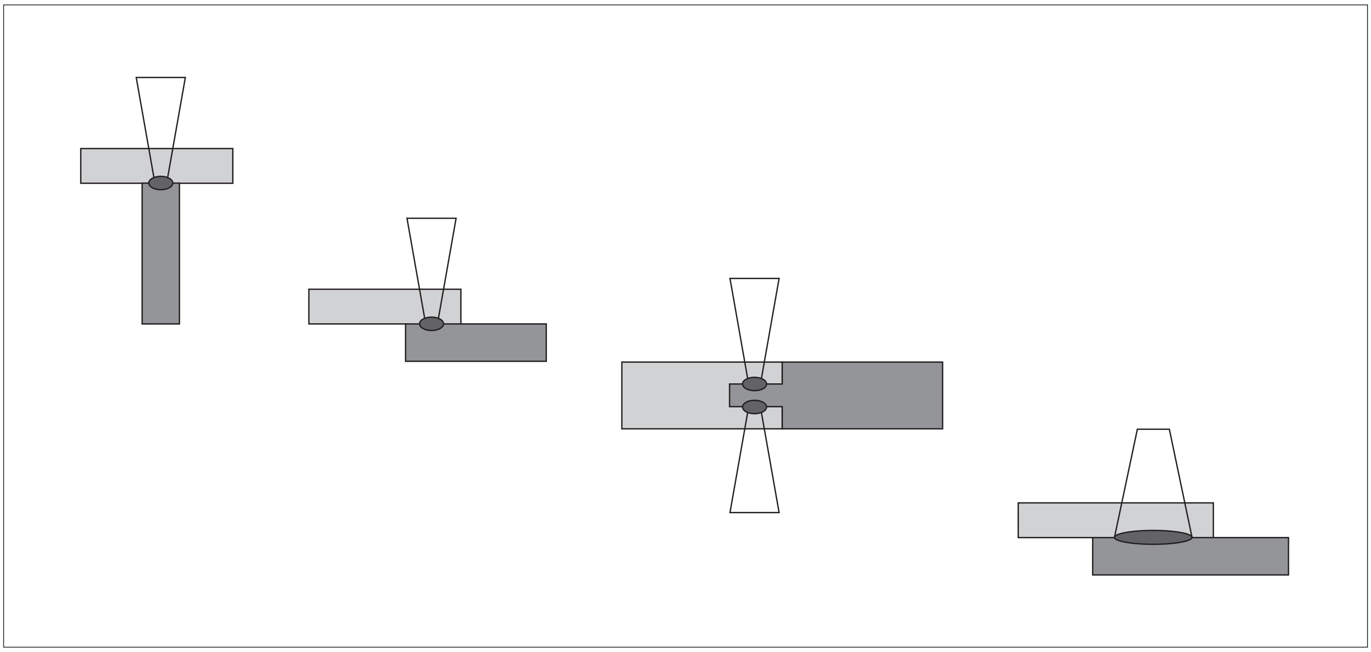


Fig. 10.95c **Variations of laser weld joint designs**

Machine Suppliers and Institutes

Various well known assembly machine manufacturers are active in “TLW”, Branson and Bielomatik of Germany have commercial laser welding machines, although their objective is not to replace vibration, hot plate and ultrasonic welding machines, but to offer it as an alternative process. Their machines have a range of laser power up to 50 W.

Institutes such as the TWI in the UK and the Fraunhofer Institute in Germany are also very experienced and have access to higher power lasers. Other machine manufacturers include Herfurth of the UK and Leister of Switzerland.

A Leister Diode laser machine is installed in Meyrin and has the following features:

Laser type =	Diode Laser
Wavelength λ =	940 nm
Max. power =	35 W
‘Spot’ size =	∅0,6 mm to ∅3 mm
Max. speed =	150 mm/s
Positional accuracy =	2 mm

Also available within the DuPont organisation is a 500 W diode laser located in Japan.

Fig. 10.95d **Laser welding machine.**

Riveting

Riveting Equipment

Riveting is a useful assembly technique for forming strong, permanent mechanical joints between parts at low cost. It involves permanent deformation or strain of a rivet, stud, or similar part at room temperature or at elevated temperatures.

Heading is accomplished by compressively loading the end or a rivet while holding and containing the body. A head is formed at the end of the rivet by flow of the plastic when the compressive stress exceeds the yield point.

Equipment used ranges from a simple arbor press and hand vice to a punch with an automatic clamping fixture for complex multiple heading operations. Examples of tools for heading rivets are shown in Figures 10.96 and 10.97. As the tool is brought into contact with the parts to be joined, a spring-loaded sleeve preloads the area around the protruding shaft to assure a tight fit between the parts. The heading portion of the tool then heads the end of the shaft, forming a strong permanent, mechanical joint.

Heading can be adapted to many applications. The following guidelines should be considered in design.

The different stages of a riveting operation are shown in Fig. 10.98.

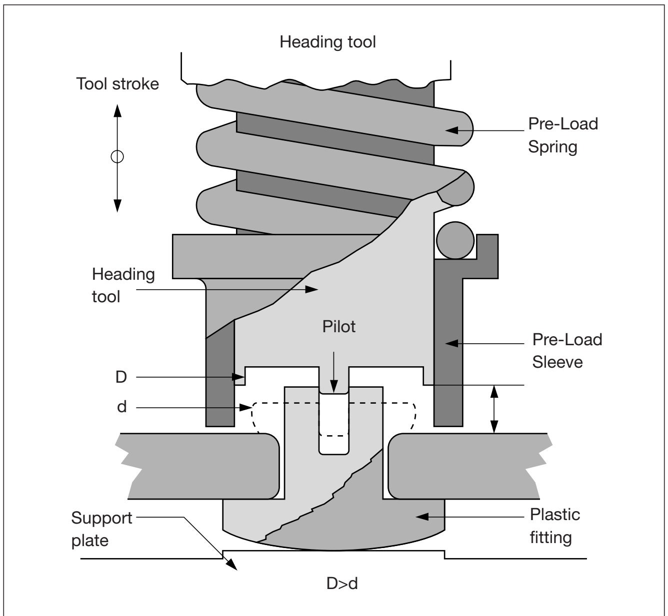


Fig. 10.96 **Heading Tool**

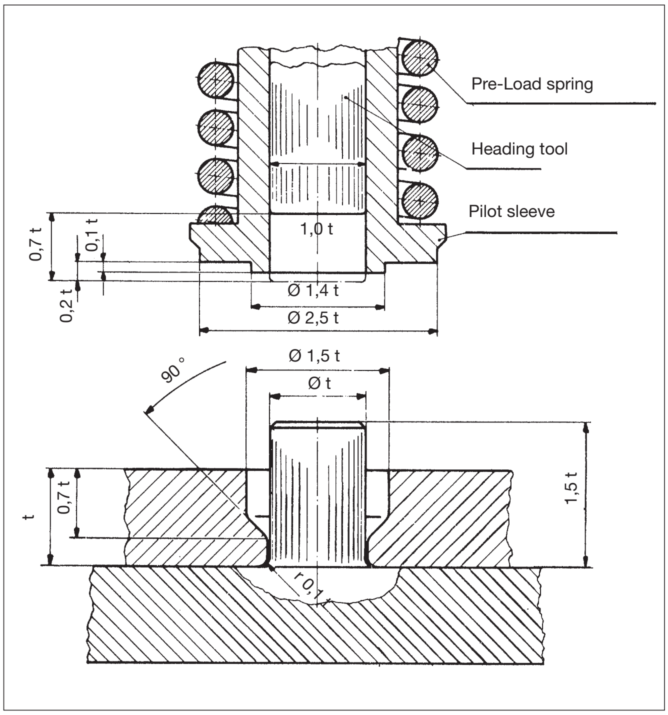


Fig. 10.97 **Heading Tool**

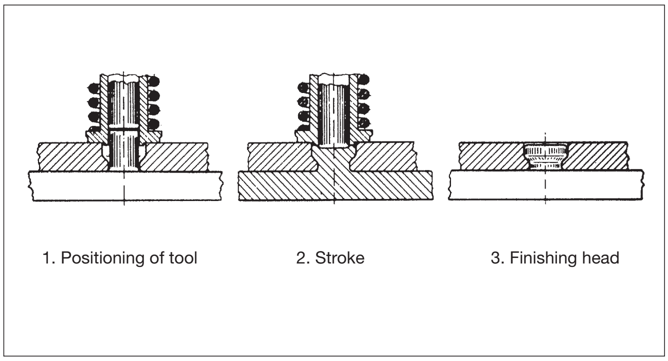


Fig. 10.98 **Riveting Operations**

Riveting Operations

Permanent deformation is produced by pressure rather than by impact.

The suggested tool and spring preload for various shaft diameters are given in the table below.

t	2 mm	3 mm	4 mm	5 mm	6 mm	8 mm	10 mm
Pre-Load Spring	20 kg	45 kg	80 kg	120 kg	200 kg	300 kg	500 kg
Tool-Load (min.)	40 kg	90 kg	160 kg	240 kg	400 kg	600 kg	1000 kg

Relaxation of Shaft and Head

The tendency for a formed head to recover its original shape after deformation depends upon the recovery properties of material used and on environmental temperature.

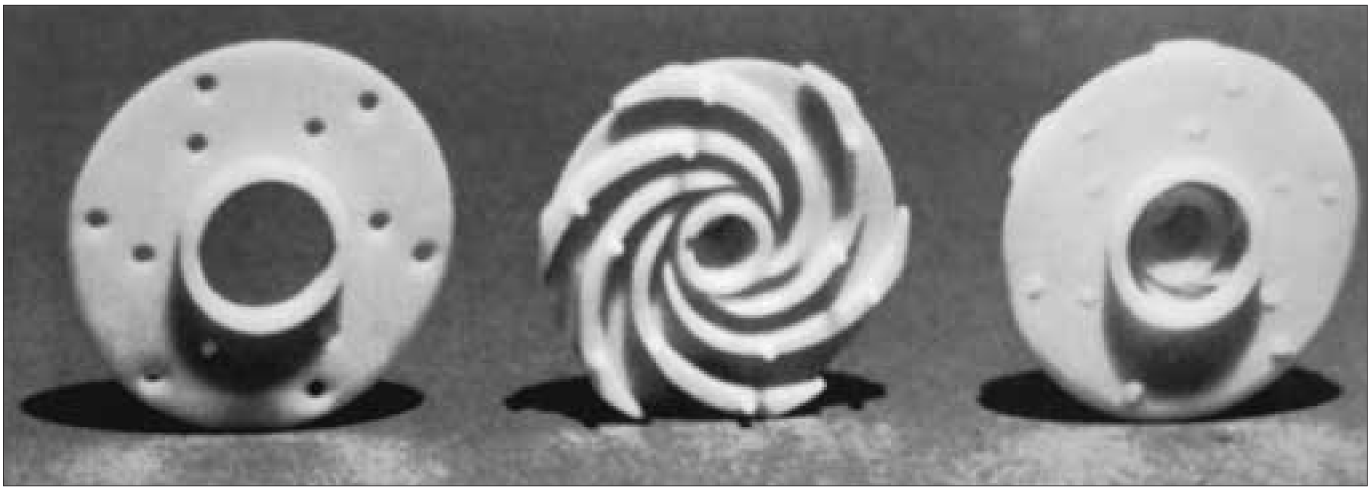
Caution

– When riveting unmodified ZYTEL® nylon it is advisable to have the part conditioned to equilibrum moisture content before riveting, in the dry state the material is too brittle. Impact modified materials such as ZYTEL® ST and ZYTEL® 408 nylon resins can be riveted in the dry-as-moulded state.

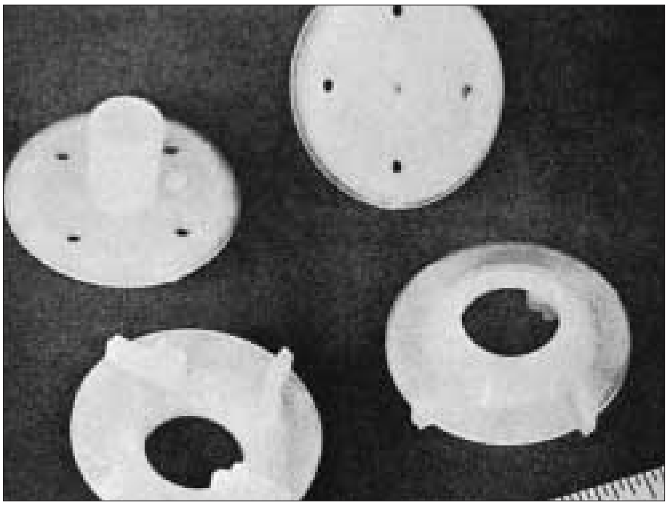
– When riveting onto sheet-metal it is necessary to remove all burrs from the edges of the hole in order to prevent shearing of the head. To ensure no recovery, as normally requested when joining sheet metal to plastic, riveting should be effected by ultrasonics.

Practical Examples

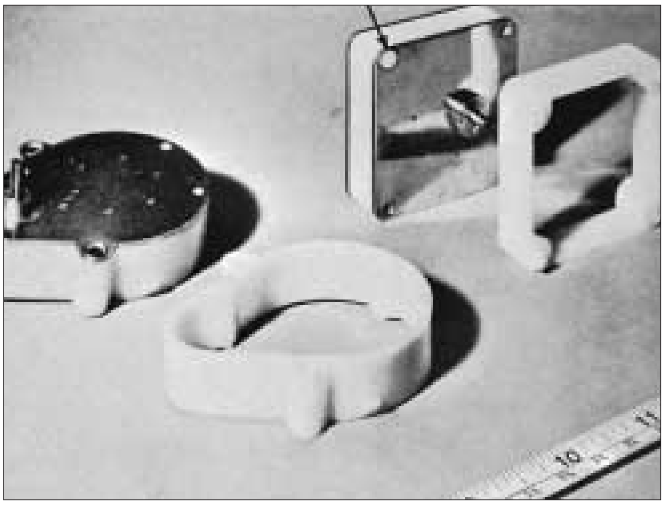
For examples of riveted parts, see Fig. 10.99.



a – Pump impeller



b – Impeller



c – Speed-reducer housing

Fig. 10.99 **Applications of Riveting**

Design for Disassembly

To improve the recyclability of plastic parts, components should be designed in such a way, that disassembly is possible wherever possible. Aspects which should be considered for this are:

- Use standard materials, whenever possible;
- When multiple materials have to be used in one part, use assembly techniques which allow easy disassembly at a later stage; see also Table 10.03;
- Disassembly, when applicable, should be possible by using robots;

  The design should allow easy cleaning and re-use of the part;
- The part material should be recognisable by part coding, for example >PA66-35 GF< for polyamide 66 with 35% glass fibre reinforcement;
- Inserts (other materials) should be easily removable, for example by using "breaking out" techniques.

Table 10.03 **Comparison of assembly techniques for plastic parts**

Assembly technique	Material combination	Recyclability	Disassembly
Screw	arbitrary	good	good, but time consuming
Snap-fit	arbitrary	very good	good, when properly designed
Press-fit	arbitrary	good	poor – reasonable
Welding	family members	very good	not possible (not always applicable)
Bonding	arbitrary	poor	poor
Overmoulding	arbitrary	reasonable	poor