**Ultrasonic welding**

When bonding material through ultrasonic welding, the energy required comes in the form of mechanical vibrations. The welding tool (sonotrode) couples to the part to be welded and moves it in longitudinal direction. The part to be welded on remains static. Now the parts to be bonded are simultaneously pressed together. The simultaneous action of static and dynamic forces causes a fusion of the parts without having to use additional material. This procedure is used on an industrial scale for linking both plastics and metals (figure 5).

![Figure 5: Differences in the process for welding plastics and metals with ultrasonics](image)

1. Anvil
2. Parts to be welded
3. Sonotrode
4. Ultrasonic oscillation

**Ultrasonic welding of plastics**

**Oscillations are introduced vertically**

Ultrasonic welding of plastics is a state-of-the-art technology that has been in use for many years. When welding thermoplastics, the thermal rise in the bonding area is produced by the absorption of mechanical vibrations, the reflection of the vibrations in the connecting area, and the friction of the surfaces of the parts. The vibrations are introduced vertically. In the contraction area, frictional heat is produced so that material plasticizes locally, forging an insoluble connection between both parts within a very short period of time.

The prerequisite is that both working pieces have a near equivalent melting point. The joint quality is very uniform because the energy transfer and the released internal heat remains constant and is limited to the joining area. In order to obtain an optimum result, the joining areas are prepared to make them suitable for ultrasonic bonding. Besides plastics welding, ultrasonic’s can also be used to rivet working parts or embed metal parts into plastic.
Ultrasonic metal welding
Horizontal oscillation direction

Whereas in plastic welding, high-frequency vertical vibrations (20 to 70kHz) are used to increase the temperature and plastify the material, the joining of metals is an entirely different process. Unlike in other processes, the parts to be welded are not heated to melting point, but are connected by applying pressure and high-frequency mechanical vibrations.

In contrast to plastics welding, the mechanical vibrations used during ultrasonic metal welding are introduced horizontally.

The mechanisms during ultrasonic metal welding

![Figure 6](image)

Principle of ultrasonic metal welding
1. Sonotrode
2, 3 Parts to be joined
4. Anvil
5. Welding area

During ultrasonic metal welding, a complex process is triggered involving static forces, oscillating shearing forces and a moderate temperature increase in the welding area. The magnitude of these factors depends on the thickness of the work pieces, their surface structure, and their mechanical properties.

The work pieces are placed between a fixed machine part, i.e. the anvil, and the sonotrode, which oscillates horizontally during the welding process at high frequency (usually 20, 25, 30, 35, 40 or 40 kHz) (figure 6).

The most commonly used frequency of oscillation (working frequency) is 20 or 25 kHz. This frequency is above that audible to the human ear and also permits the best possible use of energy. For welding processes which require only a small amount of energy, a working frequency of 30, 35, 40 or 50 kHz may be used.
Figure 7: Ultrasonic metal welding mechanism

Rough surfaces prevents slippage

The sonotrode and anvil (welding tools) usually feature rough surfaces or have a milled or ground structure (cross-ribbed or grooved structure, etc.) to grip the parts to be joined and prevent unwanted slippage.

Locally limited metal deformations

The static pressure is introduced at right angles to the welding interface. Here, the pressure force is superimposed by the high-frequency oscillating shearing force. As long as the forces inside the work pieces are below the limit of linear elasticity, the pieces will not deform. If forces surpass a given threshold value, local material deformation will soon take place. These shearing forces, at high frequency, break down contamination, remove it and produce a bond between pure metal interface. The further oscillation makes the interface
deformation grow until a large welding area has been produced. At the same time, there is an atomic diffusion in the contact area and the metal re-crystallizes into a fine grain structure having the properties of a cold-worked metal (figure 7).

**Temperature rise in the welding area**

**No fusion**

Ultrasonic metal welding is local and limited to the shear forces and displacement of intermediate layers. However, a fusion does not take place if the pressure force, the amplitude and the welding time have been properly adjusted. Microscopic analyses using optical and electronic microscopes make re-crystallization, diffusion and other metallurgical phenomena evident. However, they provide no evidence of fusion (melted interface). The use of highly sensitive thermal sensing devices in the intermediate layers shows in initial quick rise in temperature with a steady temperature drop afterwards.

**The temperature profile can be controlled**

The maximum temperature obtained is a function of the process settings at the welding equipment. An increase in welding energy likewise leads to an increase of possible maximum temperature. An increase in the static force also leads to an increase of the initial temperature, but at the same time limits the possible maximum temperature. Consequently, the temperature profile can, within certain limits, be influenced by proper machine adjustments.

The temperature in the intermediate layer is, of course, also a function of the properties of the material. The basic rule is that the temperature obtained is higher for materials with a low thermal conductivity such as iron, and lower for metals with a higher thermal conductivity such as copper and aluminium.

Temperature measurements carried for different materials with widely varying melting points have shown that the maximum temperature in the welding interface will not exceed some 35 to 50% of the melting temperature of the individual metal, provided that the proper welding parameters have been selected.

**Homogeneous and lasting joints**

**Diffusion takes place**

Ultrasonic metal welding is not characterized by superficial adhesion or glued bonds. It is proven that the bonds are solid, homogeneous and lasting joints. If, for example, a thin aluminium sheet is ultrasonically welded to a thin copper sheet, it can easily be ascertained that after a certain period of weld time, copper particles appear on the back side of the aluminium sheet. At the same time, aluminium particles appear on the back side of the copper sheet. This shows that the materials have penetrated each other -- a process which is called diffusion. This process takes place within fractions of a second.