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Process description

1 Introductions

Apart from ultrasonic and hotplate welding, "linear vibration welding" has become established particularly in the field of large-area joints in series manufacturing. The process is suitable for parts of any shape, but under the conditions that the joints allow movements between the parts to be joined.

Particularly for large (car bumpers) or thin-walled parts, vibration welding requires high expenditure for the holding tools in order to transfer the necessary friction movement evenly to the seam to be welded.

Apart from the known welding capability of thermoplastics, which are defined as polymeric compounds, it is also possible to join thermoplastic and non-thermoplastic materials. In this process, the thermoplastic material is bonded to the respective substrate material by grippage, in which the strength values depend on the structure of the respective substrate. The molten thermoplastic flows into the recesses of the non-thermoplastic surface, where it grips after cooling.

2 Process engineering

2.1 Melting by friction

Linear vibration welding is a friction welding process. In linear vibration welding, the parts to be joined are rubbed together in an oscillating, translatory relative motion under a defined pressure until the materials at the contact zones melt and the molten material can flow. After the completion of the vibration process, they are cooled under pressure to create a consistent bond between the materials.

In the vibration welding process, the welding parameters welding time $t_s$, welding force $p_s$, cooling time $t_H$, cooling force $p_H$, welding travel $S_s$, amplitude $a$ and frequency $f$ are applicable.
2.2 Cycle of vibration welding

Process phases
Within the entire cycle of vibration welding, the vibration phase during the welding time and the succeeding cooling phase in the cooling time are decisive to the properties of the welded seam which result from the welding parameters. The welding cycle can be divided into four main temporal phases, which can be characterised by the joining travel over time.

Process phases of vibration welding

| Phase 1 | Solid friction phase |
| Phase 2 | Instationary smelt friction phase |
| Phase 3 | Quasi-stationary smelt friction phase |
| Phase 4 | Dynamic cooling phase  
Static cooling phase |

Phase 1
In Phase 1, the friction surfaces of the parts to be joined are heated by friction energy to a point above the crystallite melting point or, for partial crystallines, the glass transition temperature for amorphous thermoplastics.

Phase 2
In the succeeding, instationary Phase 2, a molten film builds up and the initial flowing motion forms the weld reinforcement.

Phase 3
In the succeeding, quasi-stationary Phase 3, an approximate energy balance is achieved. The joining travel describes an almost constantly linear curve against time.

Phase 4
After the completion of the vibration phase, the joined parts cool under pressure. This cooling phase is divided into the dynamic cooling phase, in which the amplitude falls degressively, and the static cooling phase.
3 Machine technology / adjustment facilities

The linear vibration movement can be created by hydralic or electromagnetic drives.

3.1 Electromagnetic drive system

The current provided by the electrical supply passes through a generator to the electromagnetic coils. These are installed together with spring assembly in the vibration head. The vibration system is set in a linear vibration by the alternating magnetic fields. The system is returned to its initial position by the resilience of the springs.

3.2 Amplitudes and frequencies

Depending on the requirements on the welding operation, the amplitude can be changed in machines with 100 Hz working frequency from 1-2 mm and from 0.35-1.0 mm in machines with 260 Hz working frequency.

The frequency must be adjusted to the resonant frequency of the vibration system. The design properties of the parts to be joined must be taken into account in the adjustment of the amplitude. The frequency and amplitude determine the rubbing speed and thereby the energy applied to the welding zone. Increasing the frequency and / or amplitude increases the quantity of applied energy and thereby reduces the time until the molten film occurs.
Highlight – the KLN vibration welding machine

- Selectable operating mode
  - Travel welding mode
  - Time welding mode

- Working frequency f [Hz]
  - Frequency range 0-260 Hz – according to type

- Joining force Fk [kN]
  - Joining force at PP 26.7 kN – according to type

- Upper tool weight [kg] 15 - 80 kg – according to type

- AFRC Automatic Frequency Resonance Control
  A speciality of this machine is the adjustment of the resonant frequency to the respective weight of the upper tool. This technique ensures a high degree of flexibility in the design of the tools, as it is unnecessary to maintain a precise weight.

  This automatic frequency adjustment is employed when tools are changed or a new tool is commissioned. After passing through a frequency range of 280 - 150 Hz, the machine automatically adjusts the resonant frequency of the vibrating system in dependency on the weight of the upper tool.

Force-travel-time-amplitude stage control

- Force-travel-time-amplitude stage control
  During the welding process, the parameters force-travel-time-amplitude can be controlled variably by the control system in 8 stages. Amplitude a [mm]
  - The amplitude can be controlled variably by the control system during the welding process in 8 stages.
  - The amplitude is selectable from 0.35 to 1.0 mm at a frequency of 260 Hz.

- Welding force ps [bar]
  - The welding force can be controlled variably by the control system during the welding process in 8 stages.

- Welding force pH [bar]
  - The cooling force can be controlled variably by the control system during the welding process in 3 stages.

- Laser travel measuring system
  - The selectable operating mode Travel-dependant welding can be controlled variably by the control system in 8 stages.
  - Laser sensor with an accuracy of +/- 0.05 mm

- Time welding mode
  - The selectable operating mode Time-dependant welding can be controlled variably by the control system in stages.

- Control system
  - Siemens S7
  - Control unit OP 27
  - Graphic display of the welding process
  - Process parameters output to R 232 interface
  - Process parameters monitoring with actual/nominal value comparison
3.3 Cooling force, cooling time

Cooling force
The selected joint seal geometry and the correct choice of the pressing force play important parts in this. Values from experience and laboratory tests have shown that the pressing force (sealing force) should lie between 40 and 100 N/cm².

When welding is conducted with variable forces, the cooling force should be equivalent to the welding force at the end of the vibration time. Reducing the pressure on the welded seam by reduction of the cooling force can lead to a serious reduction of the welded seam strength.

Cooling time
The cooling time must be chosen to allow the seam to fall below the freezing or crystallisation temperature and to cool. This time usually lies between 1 and 5 s.

Requirements on the vibration welding machine, cooling force, cooling time
It is possible to equip the machine with a pressure stage controller. This means that the cooling can be varied during the cooling phase (4 phases). (E.g. 3 pressure/time stages.)

3.4 Welding travel

Welding travel
The welding travel is monitored by a laser measuring system integrated in the machine. The following operating states can be selected: Welding depth, Absolute component height
The achievable welding travel is influenced by the following factors.

• Amplitude
• Frequency
• Joining force, Joint geometry
• Material

Requirements on the vibration welding machine, cooling force, cooling time
Not dependant on the machine type, but on the capability of the control system.
• Welding travel can be adjusted and controlled (actual/nominal value comparison)
4 Material combinations

Welding of plastics of the same kind and type
e.g. ABS - ABS

Welding of plastics of the same kind but different types
e.g. unreinforced – reinforced

Welding of different plastics
ABS - PMMA    PPE - (PC + ABS)
ABS - PVC     PMMA - SAN
ABS - PC      PC - (PC+ABS)
ABS - S/B     PC - (PC+PBT) modified
ABS - SAN     PBT - (PC+PBT) modified
ABS - (PC+ABS) PPE - (PPE+PA)
PMMA - PVC-U  PA - (PPE+PA)
PMMA - PC     PE-HD - PE-HD/EPDM
PMMA - (PC+ABS) PP - PP/EPDM

Welding of plastics to non-plastic materials
e.g. textiles, resin compounded fibre materials

5 Tool technology

As mentioned above, the technical expenditure for the holding tools is very high to transfer the vibration amplitude evenly to the welded seam.

It must be ensured that the tools are sufficiently retained and carried in the vicinity of the welding zones. It is therefore advisable to plan Cooling aids during the development of the mouldings so that the parts are positioned correctly before they are welded.
6 Design of the mouldings

The design of the mouldings depends upon the later purpose of the finished product (quality of the welded seam). The mouldings should be sufficiently rigid, particularly when the tool cannot grip the part in the immediate vicinity of the welding surface. It must be ensured that the tools are sufficiently retained and carried in the vicinity of the welding zones.

5.1 Shape of the welding surfaces

As in all vibration welding methods, energy directors should be employed for vibration welding to achieve a favourable energy input. For example, tongue and groove seams are suitable. The design must take account of the fact that the molten material expelled during vibration welding is usually ragged, brittle and of poor appearance. It is therefore advisable in most cases to provide catchment grooves to achieve concealed seams.

6 Conclusion

Vibration welding has diverse application in industry, such as in automotive construction (welding of bumpers, instrument panels, lights, rear shelves, active carbon filters, ventilation ducts etc.). In particular, vibration welding is employed when components with large surfaces are to be joined.

7 Example application
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http://www.kln.de

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