POSSIBILITIES TO IMPROVE THE QUALITY AND THE ECONOMIC EFFICIENCY OF PRESSURE-PRESSURE-SOLDERING-JOINTS

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Abstract:

Recently, the researches have proven that application potential of the pressure-pressure-soldering-joints (PPSJ) in the industrial manufacturing process is very huge. In order to satisfy the higher customer requirements, the products should always have a higher quality with lower costs. Therefore, this paper will introduce the possibilities to improve the quality and the economic efficiency of PPSJ.

The increase of the joint quality has been created through the improvement of the diffusion coefficient, because PPSJ is assigned to the adhesive bond. According to this purpose, the training process will be optimized. Then, a new coating materials will be tested. Thanks to the automation of the pressing, training and controlling process, the manufacturing time and -cost have been reduced.

1. PRESSURE-PRESSURE-SOLDERING-JOINTS

The shaft-collar connection plays a very important role in the automotive technology as well as machine element. Table 1 shows different methods to join shaft and collar.

Table 1 Different methods of shaft collar connection

	Positive locking	Force closure	Adhesive bond
Instance	Feather key	Press joint	Welding joint
Manufacture cost	-	+ +	+
Transmission ability	+	-	+
Disassembling ability	+	-	-
Alternating load	-	+	+ +

There are some concerns relating to conventional connection such as high production costs, problems with alternating load and so on. Therefore, it is necessary to develop new connection.

1.1 Tight interference fit connection

Tight interference fit connection belongs to the force closure join connection. The most important parameters influencing on the quality of this connection are the suitable of the joining area and the interaction of forces between the each parts. As described in Fig 1.1, the formation of this joining process results from an elastic or elastic/plastic radial spanning of exterior and interior ([1], [2]).

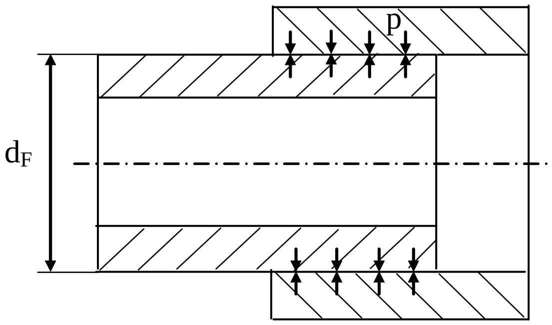

Figure 1.1 *Tight interference fit connection*

In comparison with positive locking join connection, the tight interference fit connection has many advantages. The manufacturing cost is lower due to the simple rotationally symmetric joining areas in relation to the positive locking connection. The dimensions of the tight interference fit connection are smaller then the one of other shaft collar connection. With the tight interference fit connection, it is possible to makes a perfect centring, a high concentricity of the parts, which can be joined in relation to positive locking connection.

Because the notch effect is smaller, a higher fatigue-strength has been obtained [3].
There are many investigations for tight interference fit connection, for example, an investigation of load transmission. The transmission of the torques, dynamically purely change, purely swelling torque load, bending moment transmission as well as dynamic bending moment transmission up to the combined dynamic load by bending moment, torques and transverse force for transverse pressing or long pressing connection have been examined already([3], [4]). The influence of the roughness on the tight interference fit connection behaviour has partly been examined ([5]). The methods to avoid fretting corrosion have been found such as using MoS_2 as lubricant, or phosphatising of the press area.

1.2 Pressure-pressure-soldering-joints

Pressure-pressure-soldering-joints are a combine join-connection. In this connection, the join areas are coated by a thin solder layer (Figure 1.2), and then it is assembled by along or transverse presses. Thanks to the joining and operating load, a local adhesive bond connection in solid state has been created by themselves ([6], [7]).

Pressure-pressure-soldering-joints inherit the advantages and eliminates the disadvantages of the tight interference fit-connection and press solder connection. The advantages of pressure-pressure-soldering-joints are:

- Pressure-pressure-soldering-joints are characterized by significantly high transmission ability. As a result, the join length is reduced. Furthermore, the tolerance field is expanded.
- The join connection can be disassembled and reused.

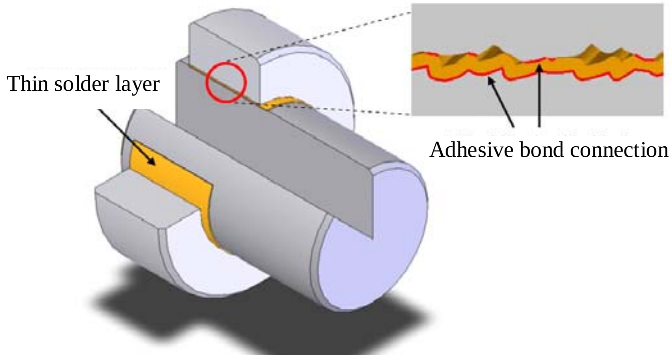

Figure 1.2 *pressure-pressure-soldering-joint [8]*

The first investigation of the pressure-pressure-soldering-joints has been carried out by Füssel in 1984 at the Chemnitz University ([6]). Thanks to apply a thin intermediate layer from zinc or copper, it is possible to increase the ability of moment transmission. The new invention of Füssel opened many new investigations. The behaviours of pressure-pressure-soldering-joints during static, dynamic and combined torque load or rotating bending strain have been examined by Füssel, Lipoth, Schnik ([6], [7], [9]). The technical and scientific bases for training have been discussed by Lipoth, Schnick and Ramminger ([10]). Tersch has researched the shape strength of the pressure-pressure-soldering-joint.

2. IMPROVEMENT OF JOINT QUALITY

One mechanisms of the pressure-pressure-soldering-joint is adhesive bond. Significantly, the quality of the adhesive bond-connection depends on the diffusion coefficient. Therefore, it is necessary to improve the diffusion coefficient.

2.1 Influence factors of the diffusion process

Diffusion is a physical process, which leads to a uniform distribution of particles and thus a completed mixing of two materials [11]. The diffusion process depends on many factors, i.e.:

- **Temperature**: the diffusion coefficient is proportional to temperature, because diffusion is a thermally activated process. The Arrhenius equation described the relation between diffusion coefficient and temperature ([12], [13], [14], [15]).

  $$D = D_o \cdot \exp\left[-\frac{H_{LD}}{kT}\right]$$

  Where H_{LD} is activation enthalpy; D_o is constant for the regarded systems; T is temperature.
- **Concentration**: The Fick's law pointed out that an element within a diffusion connection diffuses from the high concentration range to the low concentration range, that means the more large concentration difference is, the more large diffusion coefficient is ([13], [16]).
- **Vacancies**: Vacancies are lattice defects in point form. Beside the concentration gradient, the vacancy concentration is also an important driving power for diffusion ([13], [16], [17]).
- **Dislocations**: Dislocations are lattice defects in line form. Diffusion coefficient at constant temperature rises with the increase of tilt angle or with the increase of dislocation number ([13], [17], [18]).

- **Mass**: Linearly, the diffusion coefficient depends on the oscillation frequency of the diffusive particles ν.

$$\nu = \frac{1}{2\pi}\sqrt{\frac{K}{m}} = \sqrt{\frac{G_i^M}{2md^2}} \qquad [13]$$

  Where: d = jump wide, G =: partial free Enthalpy, G_i^M = activation mountain of the height.

  That means, ν is inversely proportional to the square root from the mass of the jumping atom.
- **Pressure**: The active volume resulting directly from the pressure has influence on the diffusion coefficient. That means, the diffusion coefficient decreases with increasing pressure ([13]).
- **Driving power of chemical diffusion**: It is the chemical potential ([19]).
- **Solidifying- or liquidizing temperature**: the lower the solidifying- or liquidizing temperature is, the higher the diffusion coefficient is ([16]).
- **Plastic deformation**: there is a sign for the fact that at deeper temperatures, the influence of sculptural deformation on the diffusion is greater ([16]).
- **Surface structure**: the surface structure (atomic steps, microscopic roughness and penetration point of dislocation) has also a determining influence ([20]).

2.2 Possibilities for improvement of diffusion process

As discussed in 2.1, the diffusion process can be accelerated by different influence factors. The problem is how to change these influence factors. In the pressure-pressure-soldering-joint the following factors are most interested.

2.2.1 Temperature and plastic deformation

We can increase the temperature in different way such the heating of shaft and collar, using of electric current over the contact places between shaft and collar or by frictional energy from relative movement between shaft and collar.

If we heat whole shaft and collar, physical properties of both parts will be changed (e.g. structure changes). This will be not desired. With the relative movement, the frictional heat is transferred almost directly in the join area, only a small part is transferred on shaft and collar body, so that structure changes are excluded. Moreover, the relative movement creates also plastic deformation. Therefore, the increasing temperature is preferred by frictional energy.
Since 1984, Füssel has created friction energy by pressing out and in of join connection and rotating joint parts of each other as well as by dynamic load ([6]). After that, Lipoth has performed the training of pressure-pressure-soldering-joint by rotating in variable direction with small velocity (5^0/min) and small rotation angle up to slide (20 cycles), following load by torsion vibrations (150000 cycles, 25Hz) without complete slipping and renewed rotation in variable direction (20 cycles) ([21]).
The two above training methods are good. However, it is time-consuming and the moment transmission ability is still not enough. The above methods are not suitable for industry production, where short cycle time and high moment transmission ability are required. Therefore, it is necessary to optimize training process.

With experiments for gear elements (Fig. 2.1), the optimal training result with a speed of 600^0/min has been achieved as shown in Fig. 2.2.
At this speed, the process time is less than one minute.

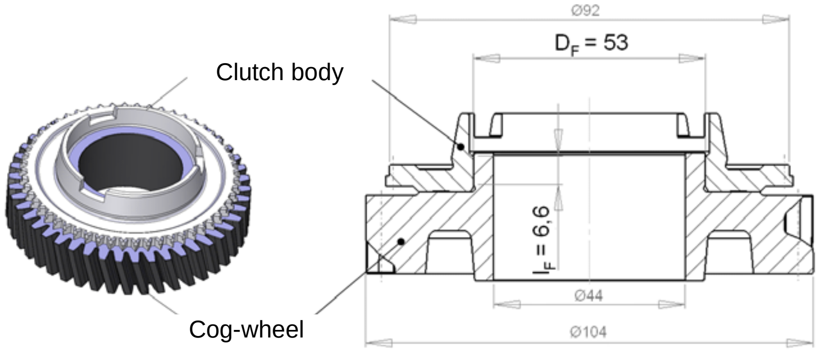

Figure 2.1 *Element group 3. Gang*

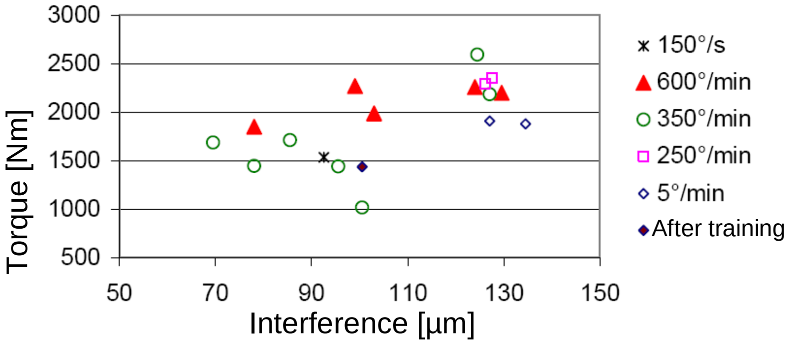

Figure 2.2 *Training moments of PPSJ depending on velocity and interference*

2.2.2 Soldering material

The creation of the joining will be affected positively, if the following requirements of combine material are satisfied:

- The difference of atom radius of jointed parts should be smaller than 8 to 15%, because only under this condition an admission of the atoms, it is possible to store the atoms in the host lattice.
- The crystal lattice structure should be as similar as possible, so that the atoms can take easily similar energy or priority places.
- The electronegativity should not be too different, otherwise the risk of formation of inter-metallic phase would occur.
- Temperatures above the critical recrystallisation temperature ($T_{RCZinc}=4^0C$; $T_{RCCupper}=269^0C$) are advantageous and affect aiding the diffusion processes.

The above requirements are sufficiently fulfilled by e.g. zinc, copper, aluminium, nickel or silver in connection with steel as base material.

The investigations of zinc and copper have been carried out by several authors. However, the rest materials have not been investigated yet. In a new attempt, we have used nickel and silver. The results are shown in Fig. 2.3.

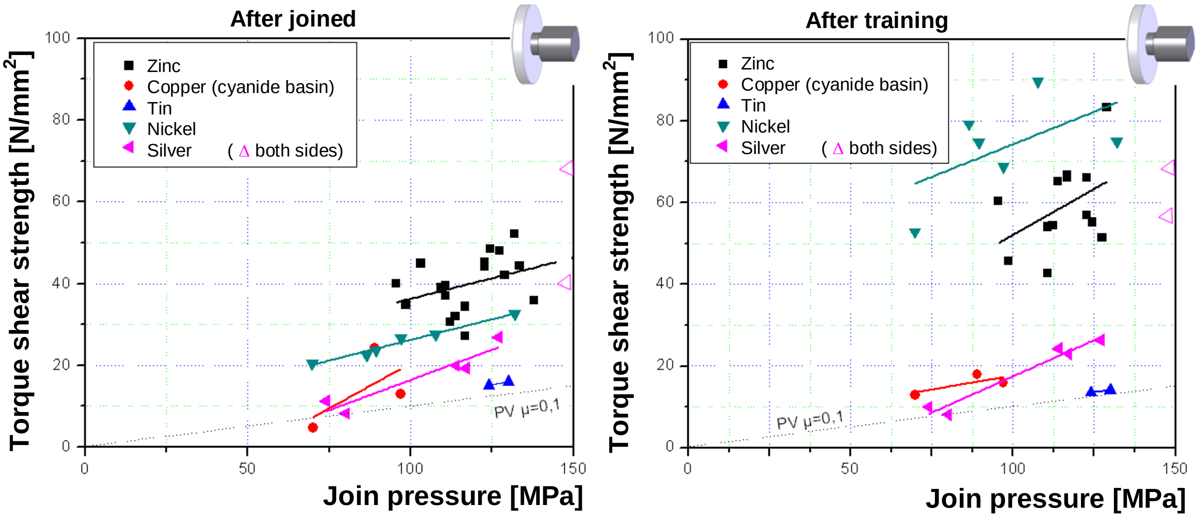

Figure 2.3 *Achieved connection strength at various soldering material*

Fig 2.3 shows clearly that after training the nickel gives the greatest connection strength (or torque shear strength). The reason is that the nickel has higher chemical potential in comparison with other material.

There are still no experiments with the aluminium, because it is difficult to coat aluminium by galvanic technique. However, aluminium can be coated by other technique, which is mentioned later.

3. IMPROVEMENT OF ECONOMIC EFFICIENCY AND ECOLOGY

3.1 Alternative coating techniques for the pressure-pressure-soldering-joint

What the pressure-pressure-soldering-joint is created now, so a soldering coated onto shaft surface due to galvanic technique. We obtained a good strength and a good joint. Nevertheless, the galvanic technique has bad impact on ecology. Moreover, it is difficult and expensive for small series production and for automation. For these reasons, it is necessary to replace galvanic coating technique by other technique. Hereafter, there are several alternative coating techniques:

- **Thermal spraying:** the DIN EN 657 defines thermal spraying as a technique, in which spray materials inside or outside of spray device are partly or completely melted and hurled onto a prepared surface. The technique has a large coating range and is connected with extensive spraying dust. In addition, there are a high oxidation portion in the coating and thermal effects on the surface. The coating thickness is in range of 10µm to several millimetre ([23]).

- **Cold spraying**: In the cold spray process, a gas is accelerated to supersonic velocity in a de-Laval-type nozzle. The coating material is injected into the gas jet under powder form in front of the nozzle and then propelled onto the substrate. Above a certain particle velocity, which is characteristic of the respective coating material, the particles form a dense and solid adhesive coating upon impact. To this end, the particles must undergo a deformation. Heating up the gas jet increases both the flow velocity of the gas and the particle velocity. The relating rise of particle temperature assists the deformation upon impact. However, the gas temperature is clearly lower than the melting temperature of the coating material ([24]). It is not necessary to take the damage of the substrate by thermal effects into consideration. The coating process can take place without mask. Moreover, oxidation and other phase transformation can be avoided. A coating thickness within range of 5µm to10µm can be created ([25]). These advantages are good conditions for pressure-pressure-soldering-joint, but the cold spray equipment is expensive.

- **Friction surfacing:** Since 1958, besides intensive and extensive research in the area of friction stirring, the investigation about friction surface has been carried out. Researches have investigated friction surface with coating material in form of a rod (Figure 3.1 a, b, d) or in form of fine metallic powders (s. Figure 3.1 c).

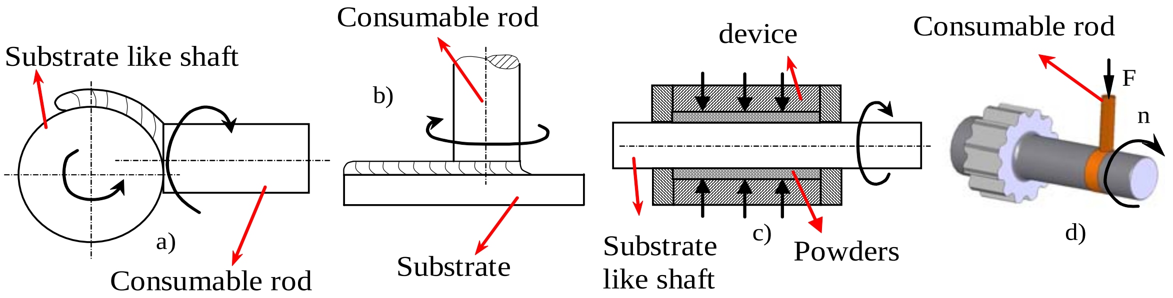

Figure 3.1 *Different types of friction surface technique*

The principle of this technique is the rotation of the coating material under pressure on the substrate or the coating material under pressure on the rotating substrate. Because of the friction generated at the rubbing surface between substrate and coating material, a lots of friction heat has been created. A certain time later, the contact ends of coating material becomes to visco plasticize or melt. After that, coating material can be transferred onto the substrate surface. Due to the relatively simple equipment, this technique is economical in comparison with the other techniques.

The three mentioned techniques have many advantages but also disadvantages. However, they can replace the galvanic technique. Moreover, it is also possible to coat aluminium. An investigation of Füssel et al. determined that shear strength in axial direction of defatted pressure-pressure-soldering-joint, which is coated by spray technique, is greater than which is coated by galvanic technique ([26]). It requires however many attempts to implement those technique for pressure-pressure-soldering-joint and to replace galvanic technique.

3.2 Automation of production processes

So far the production of the pressure-pressure-soldering-joint has been implemented only by discrete steps. This is the reason for extending the manufacturing time and manufacturing costs. Such thing is not good for a series production, where the cycle time and the manufacturing costs are very important. In order to improve the manufacturing costs and the cycle time, it is necessary to automate the production process.

With the co-operation from SITEC and FINZEL, we have automated the galvanic process and the pressing-, training process.

a. Automation of the galvanic process:

In principle, it is difficult to automate a galvanic process. However, we can carry out the automation for the simple workpiece. For example, for automating a shaft, we can use an automation line in form a closed conveyor belt. Input is a workpiece and output is a finished product or a galvanized workpiece. In this production line, the ungalvanized part of workpiece will be covered to protect from influences of galvanic process. Then, the coating parts will be cleaned. After that, it will be galvanic coated. At the end, the workpiece will be uncovered and cleaned again. All above steps will take place continuously and automatically.

b. Automation of the pressing- and training process:

A module for pressing and training procedure has been set up. On the module, you can press firstly the shaft to collar together, then the static moment is examined. If the static moment is already enough, the training procedure will not take place. Conversely, the training process will be started. If the training procedure finishes, the static moment will be examined again. These processes are developed and automated in a module as shown in Fig. 3.3.

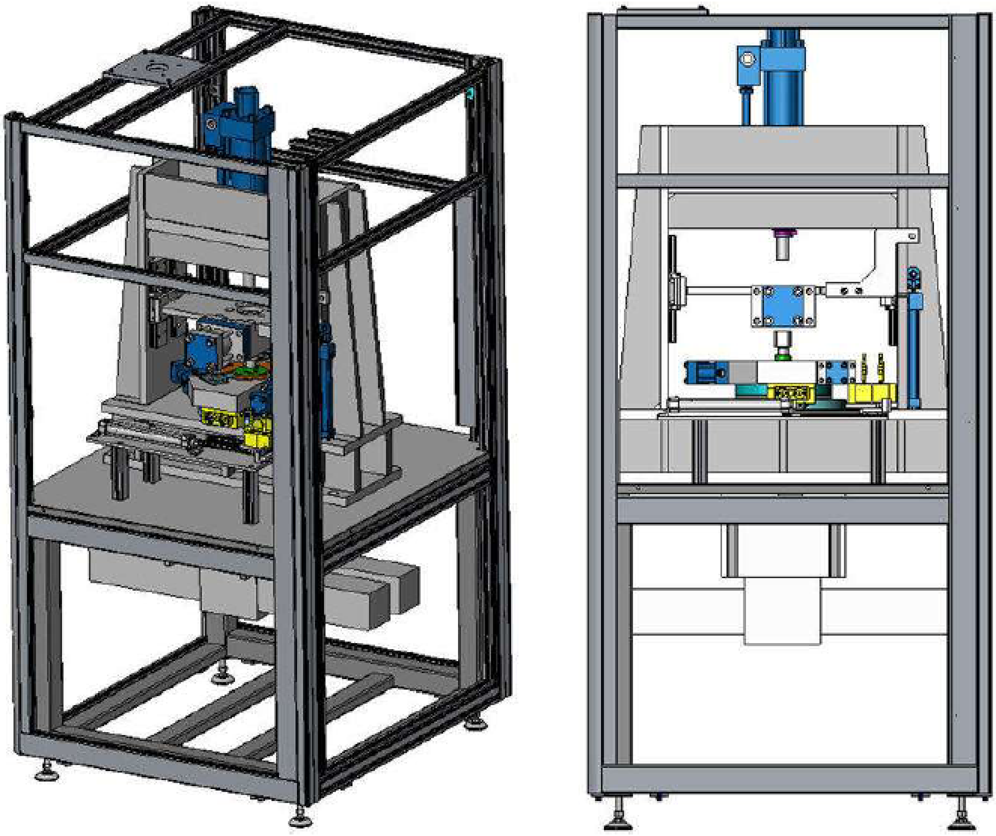

Figure 3.3 *A complete view of the device built in a Variomodul 1300 of SITEC*

With the device described in Fig 3.3, it is possible to carry out three processes (Pressing, training and controlling) continuously. The result is a confidence of the joint quality or joint connection and time saving.

4. CONCLUSIONS

The possibilities for the improvement of the join connection quality and the economic efficiency of the pressure-pressure-soldering-joint have been found. With the use of nickel as coating material, the joint quality has been improved clearly. For a specified problem, a training process can always be optimized, so we can make the training time shorter.

However, it is necessary to investigate more the other possibilities such as process combination or alternative coating processes.

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