Abstract: Clinching as an alternative joining technology to welding or bolting today is restricted up to circa 4mm single sheet thickness. There is no industrial experience in clinching higher sheet thickness up to 10mm. However, the branches of industry working with thick sheet metal (utility and rail vehicle engineering, shipbuilding and general structural steel engineering) represent a major potential for using this highly efficient and economic joining technology. Thus the need arises to predict the process conditions and joint quality as well by experimental and numerical analysis. This paper demonstrates investigations in both fields to understand the impact of relevant parameters and restrictions of thick sheet clinching.

Key words: joining, clinching, fatigue, distortion, accessibility

The principle terms and geometry parameters of a clinched joint are shown in Fig. 1 whereas Fig. 2 shows the clinching process in three steps. There are descriptions of applications [3,4,5] and standard procedures [6,7]. Special clinching variants [8,9,10] and hybrid technologies [11,12] are described. The complexity of the clinching procedure is defined by a number of significant variables (Table 1).

**Fig. 1. Principle geometry of a crosscut**
Fig. 2. Clinching process

Table 1. Principle geometry of a crosscut

<table>
<thead>
<tr>
<th>tool parameters</th>
<th>process parameters</th>
<th>material parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>punch: diameter, radii, angles</td>
<td>blank holder: force, spring stiffness</td>
<td>thickness, flow curve, pretension (for both: upper and lower sheet)</td>
</tr>
<tr>
<td>die: diameter, depth, radii, angles</td>
<td>machining: force, stiffness, velocity</td>
<td></td>
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<tr>
<td>blank holder: force, spring stiffness</td>
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Fig. 3. Steps in the clinching process and correlation to the stroke-force-curve; S380 / S235 6+4mm; d₀: 30 mm; strain with color bar from 0 to 2

To understand the whole process detailed material flow and hardening has to be considered (Fig. 3). Before offsetting there is needed a force for fixing the sheets on the die that is applied by the blank holder. Plastifying the material in the “offsetting” step involves a substantial increase in force. The increasing material upsetting between the punch and bottom of the die causes the material to flow radial and therefore to form the undercut between the two pieces of sheet metal to be connected. The maximum force is reached at the point of the maximum punch stroke.

2.2 Predictability

Due to the large number of variables in the clinching process (Table 1) analytical methods to describe the process are limited. [13,14] use a volume based approach to define suitable tool geometries. First research in adapting existing analytical approaches for calculating the force and the stresses in the tool were done by [15]. To predict force and tool geometry as well as the final joint geometry, especially neck thickness and undercut, FE-analysis is an instrument often used [16,17,18,19,20,21,22,23,24]; also predicting process details including mathematical methods [25,26,27] or process design methods [28].

Fig. 4. Verification of simulation and experiment; S380MC – 6mm in S380MC – 4mm; die diameters D₀ = 16/30mm; punch diameters D₀ = 10/20mm
As a basis for numerical simulation one main parameter is the flow curve of the sheet material. Regarding the very strong deformation in the clinching process experimental data for very high values of strain are needed. This data is carried out in compression tests using round blanks. In Fig. 4 is shown the verification of simulation and experiment for the material combination S380MC (6.0mm) in S380MC (4.0mm). As to be seen, there is a good correlation between the force-stroke-curves in experiment and simulation and between the geometrical data as well. The proved predictability of FE-analysis is the basis for further numerical investigations on the thick sheet clinching.

In Fig. 5 cross correlations between parameters on the basis of FE-analysis are shown for the small clinch joint with a die diameter of 16mm. The diagram illustrates the complexity of the clinching process and the effect of changed parameter values on the joint quality. In the considered room of variation the raising punch diameter leads to an increasing undercut. In contrast the effect of the die depth on the undercut is strongly nonlinear in this area and the minimum value of undercut for each punch diameter depends on the die depth. Such correlations can be easily studied in numerical analysis whereas the expenses are very high in order to describe these relationships experimentally.

3. PROPERTIES OF CLINCHING CONNECTIONS

3.1 Joint geometry

As already pointed out in chapter 2.2 the geometrical parameters of clinched connections can be identified in experimental studies and numerical analysis as well. The neck thickness $t_n$ and the undercut $f$ are the most important parameters regarding the joint strength whereas the bottom thickness $t_b$ is very important for non destructive quality control. Based on a joint with known neck thickness, undercut and bottom thickness it is possible to draw conclusions from the bottom thickness to the other two parameters.

As shown in Fig. 6 the correlations between the tool parameters and the joint geometry are sometimes difficult to describe and seldom linear. Supplemenal the geometry is affected by a lot of other parameters, shown in Table 1. To get information about the dimension amount of the influence on the clinch joint geometry of all these parameters sensitivity studies have to be done.

![Fig. 6. Tendencies for joint dimension vs. joint geometry and force](image)

3.2 Static and fatigue strength

Laying-up structures is only possible with known strength values of the connections. The demand on the joints geometry is varying depending on the appearing load: shear tension, pullout or peeling load. For shear loaded joints the focus is on in tendency to maximize the neck thickness. In contrast for peel loaded joints the undercut should be as large as possible.

Fig. 7 shows the force-stroke-curve for the three point (die) dimensions of 16mm, 22mm and 30mm of the material combination S380 (6mm) in S235 (4mm). The increasing point dimension has an impact on the joint strength and also on the required energy to destroy the joint.

![Fig. 7. Joint strength, typical curves for quasi-static testing, S380 (6mm) in S235 (4mm); Die diameters 16/22/30mm](image)

An example for fatigue level is shown as showcase in Fig. 8 for the same material combination and the middle die dimension of 22mm. HCF (high cycle fatigue) is on a high level compared to the quasi-static strength, about 62%. This is similar to the known level of thin sheet clinching. As to be seen in Fig. 8, the failure mode can change according to the load level. In the pictured case it changes from neck fracture for high load levels to a fracture in the sheets in / near the joint using lower load levels. Hitherto investigations show, that the failure mode has a significant influence on the fatigue strength.

![Fig. 8. Joint failure mode, S380 (6mm) in S235 (4mm); Die diameters 16/22/30mm](image)
Fig. 8. Joint strength, typical fatigue curve, S380 / S235 6+4mm

Summing up the results of joint geometry and joint strength following conclusions have to be pointed out: Input parameters must be adjusted according to requirements. If small flanges or joining forces are required, small spot diameters will be selected. If high strength is required, big tool diameters will be used.

3.3 Distortion

Local radial flow inside a clinch spot is not constant over the thickness of both plates. Local strain vectors inside the spot are caused by radial and bending load to the structure. Global elastic deformation of the structure is the consequence. Blank holder force variation can minimize the bending portion of the load. To quantify the global distortion, which is induced by this local deformation, a 3.0m x 1.0m framework structure was assembled by clinching. This framework and the measured distortion of the structure are shown in Fig. 9 and 10.

Fig. 9. Framework structure; S355MC; thickness combinations: 6mm + 6mm and 6mm + 4mm; clinching with a die diameter of 22mm

To quantify the distortion the framework was optical measured with the GOM TRITOP system. Fig. 10 shows the vector plot of distortion in y-direction comparing the framework before clinching and after clinching. The overall distortion in this direction is 5.57mm, whereas the distortion in the other two directions is nearly zero. Considering the very low stiffness in the y-direction and the length of the assembly of 3.0m this distortion is very low.

Fig. 10. Measured distortion in Y of the steel frame x: 3.0m; z: 1.0m

4. LIMITS

4.1 Joining equipment / accessibility

Standard equipment in thin sheets are C-frames with 50kN. For clinching thick sheets frames up to 1000kN are required (compare with the needed forces in Fig. 4). Next to the task (material thickness and strength) the outer point diameter $d_0$ is much above all important for C-frame-force. With force and throat depth the dimension of the frame is determined and so accessibility (Fig. 11). Alternatively a single or multi spot joining operation using a conventional press or press brake is conceivable. The necessary access on both sides with a C-frame is one of the strongest limits.

Fig. 11. Testing accessibility of a C-Frame on a clinched construction (source: Eckold GmbH)

4.2 Material restrictions

The preferred joining directions for clinching, thin sheet as well as thick sheet, are "thick to thin" and "hard to soft". If thickness or strength of the plates are on same level or inverted ratios the joint strength will be degrade. One further application limit regarding the material is elongation at material fracture. When using brittle or high strength material a fracture of the neck or die side cracks may occur during the clinching process. In this case a process layout focussing low tensile stress and low deformation level in the sheets is required – best to design with numerical simulation.
5. CONCLUSION

Clinching of thick sheet with single thickness from 4mm to 10mm is possible with a performance comparable to the state-of-the-art clinched joints in thin sheet. The good numerical forecast is the basis for further numerical investigation on size effects, functional relations and sensitivity studies on the clinching process. However, general statements for tool and process design are not deliverable yet because of the complex correlations between the parameters and the clinching result and because of the changing boundary conditions for each case of application.

Main advantages are the process safety and a better ratio in price vs. strength (€ / kN) compared to welding or bolting, especially when going to mass production. The high fatigue level and the low structure distortion are further benefits of clinching in thick sheet applications. The main disadvantages are the limited accessibility with C-frames and a restriction to overlap joints with restricted thickness a limited ratio of the joined material.

6. REFERENCES


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