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Experiences in Shear Connector Welding on Steel Components

Joining Dissimilar Aluminium Alloys by Resistance Spot Welding

Experiences in Shear Connector Welding on Steel Components: Blowing Effect Under Control

Drawn arc stud welding is a long-established welding process used in many fields of application. Here, full-surface welding of the cross-section and short welding times with high amperages are particularly noteworthy procedures. These, in addition to dispensing with filler material, contribute to meeting the current demand for saving energy and sustainability. However, the high welding current also generates a strong magnetic field with the consequence of diverting the electric arc, especially with large stud diameters (blowing effect). This causes lop-sided melting of the stud tip, which in turn may lead to malfunctions in the process and non-conformity of welding results with the relevant regulations.

Fig. 1: Anchor bolts, produced from individual parts and welded on manually (© Trillmich)

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Fig. 2: Example of an ETA for steel components with shear connectors (© Bolte GmbH)

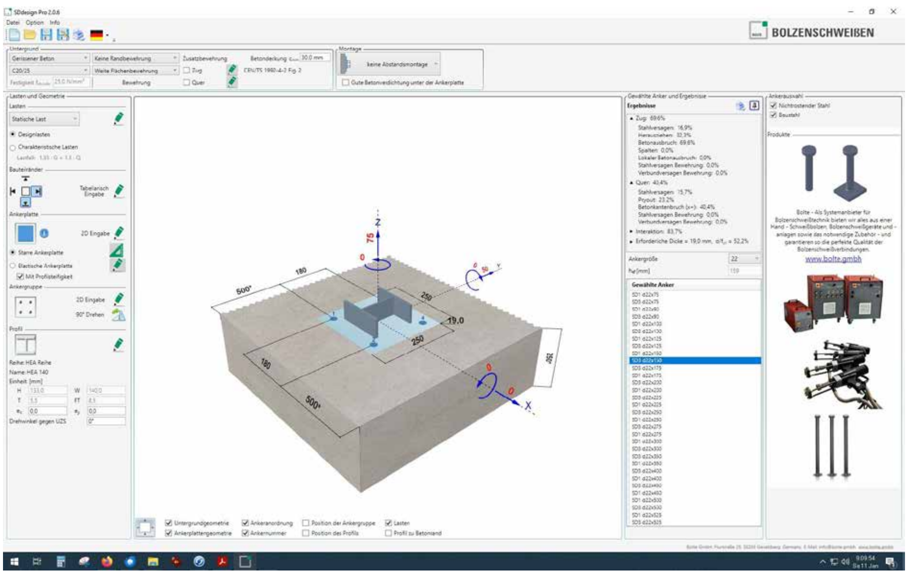

Fig. 3: Dimensioning program for steel components (© Bolte GmbH)

The areas of application for steel components with welded shear connectors are numerous. They are in demand wherever connections between steel structures and solid construction are required. Shear connectors have proven their worth for decades and almost everywhere replaced claws or reinforcing steel hooks previously in use. Their advantage lies not only in the fast-welding process, but also in the possibility to perform structural analyses. These are based on European technical standards such as EN 1992-4 and the ETA (European Technical Assessments) from manufacturers, e.g. ETA-11/0120. Accordingly, such components with shear connectors (*anchor plates*) are able to absorb forces and torques from all directions, and in combination with each other as well.

Previously, home-made anchor bolts had established themselves in several countries (**Fig. 1**) which, however, were neither subjected to an ETA, nor could they be justified from an economic point of view. According to the relevant ETA (**Fig. 2**), the use of EN ISO 13918 standard shear connectors is specified, which must be welded on by drawn-arc stud welding. Consequently, fillet welding of shear connectors is non-compliant with the rules. Manufacturers often provide programs to assist with the dimensioning of steel components (**Fig. 3**).

A special characteristic of stud welding – the blowing effect

Stud welding is an automatic welding process, therefore one could assume that a flawless result is guaranteed by simply setting the right parameters. Because this is not the case, however, the EN ISO 14555 Standard, Chapter 6 [1], has also laid down certain requirements for the operating staff. In this paragraph of the standard, a rather subtle reference is made to a special characteristic of stud welding in contrast to the commonly used welding processes. The operators

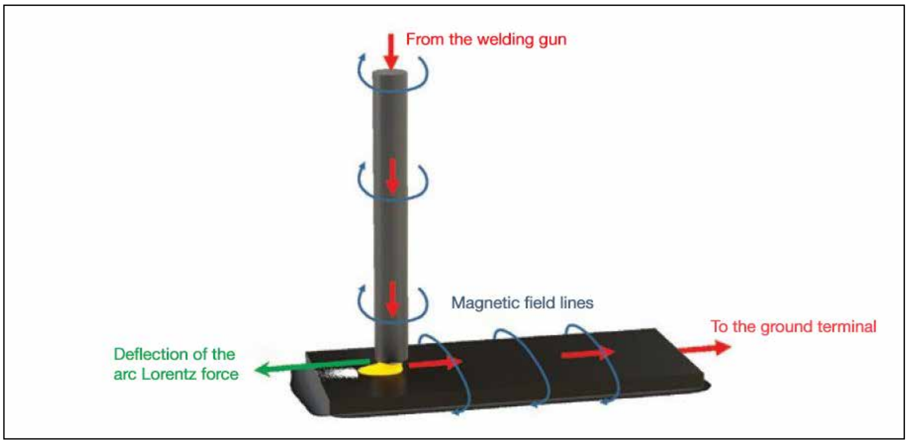

Fig. 4: Drawn arc position (yellow area) with 2,000 A welding current and one-sided ground clamping (© Marcus Trautmann)


Fig. 5: Slanted melt with plunge impediment (© Trillmich)

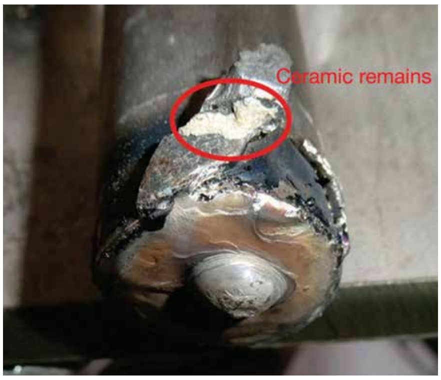

Fig. 6: Splashes caused by a blowing effect prevent the plunge. (© Trillmich)

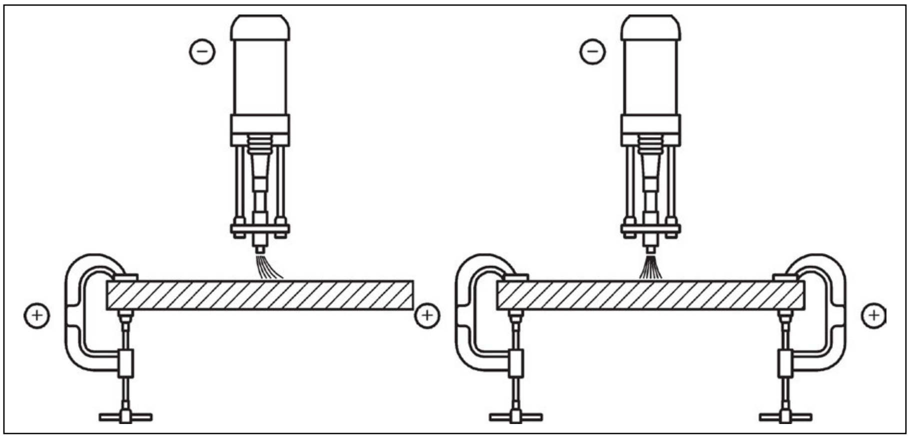
Fig. 7: Drawn arc deflection caused by one-sided ground clamping and remedy (© [2])

are required to ensure *suitable attachment of the ground cables and even distribution of ferromagnetic masses*. What does that mean?

Everyone familiar with welding technology also knows the meaning of the term *blowing effect*. It describes the magnetic deflection of an electric arc from the planned direction. **Fig. 4** illustrates this very clearly by showing the conditions prevailing in a stud weld with 2,000 A using one-sided ground clamping. A magnetic field is generated perpendicular to the direction of the current, which, in turn, generates a force directed vertically to its lines. The consequence is a deflection of the arc, depending on the strength of the current.

The result is slanted melting of the stud tip, combined with an incomplete weld collar and frequently a slanted positioning of the stud as well, due to angle shrinkage. During the welding process, the weld pool already flows to one side like on a slanted plane (**Fig. 5**). Droplet short circuits causing heavy splashes are the consequence. If such splashes solidify between the ceramic ferrule and the stud, this will hinder the stud's plunge movement (**Fig. 6**).

Practical advice

In relevant specialist literature, e.g. [1], descriptions of remedial actions can be found, such as welding at an equal distance from both ground clamps (**Fig. 7**) or the use of equalising masses. However, these instructions are just of a basic nature, the actual situation is very often quite different. In most cases, consistently good results can also be achieved with some experience, as illustrated by the examples in **Figs. 8 and 9**.

The following three components must be balanced against each other:

1. The ground clamp steers the arc away from itself;
2. The edge of the workpiece directs the arc towards the centre of the plate;
3. An exterior welding cable connected to the gun directs the arc away from the operator.

According to experience, the blowing effect increases with decreasing thickness of the metal sheet, decreasing distance from the edge and decreasing size of the workpiece. This also means that high-quality welds of shear connectors on the corners of plates are more difficult to obtain than good welds along the sides.

For mass production of steel components, the recommendation shown in **Fig. 10** is often found. Here, the sheets should be placed on a welding table so closely next to each other that the individual sheets all taken together react like a single large sheet, because the magnetic field is able to spread to the neighbouring sheets during welding. Next, the studs at some distance from the edges are welded first, then the plates are re-arranged several times to avoid welding close to the edges. In practice, however, the plates often do not lie evenly on the welding table, whose influence depends on magnetic contact with the plate just being worked on. What is more, the edges are not always smooth enough to provide close contact with the neighbouring plates.

Significantly more consistent results can be achieved by working as illustrated in **Fig. 11**. The numbers stand for:

1. Using only one ground clamp, placed diagonally opposite to the welding point
2. Decoupling of the workpiece from ferromagnetic masses (the welding table!)
3. Depending on the thickness of the workpiece: placing a balancing mass between the ground clamp and the welding point – this is very important! The balancing mass must be capable of effective magnetic coupling to the workpiece, so it must have a smooth underside. A small lifting magnet would be suitable.
4. Directing of the exterior gun cable towards the ground clamp of the machine
5. Holding the welding cable at some distance from the workpiece

Differences between ferritic and austenitic materials

With ferritic (magnetisable) steel, the workpiece itself acts as a balancing mass, which means that it "catches" the magnetic field lines, so that they are less capable of deflecting the arc. The thicker the plate, the lower the blowing effect. But what happens in the production of austenitic anchor plates? With non-magnetic workpieces, the blowing effect is considerably stronger, since the workpiece presents to the magnetic field no more resistance than the ambient air, so that the magnetic field has a significantly stronger effect on the drawn arc. Such anchor plates are widely used in large quantities for nuclear applications. But especially in this area, the quality standards in production are set extremely high, which applies to every single stud on the plate. Repairs are either not permissible at all or permitted only to a limited extent. How can the reproducibility of the welding process be ensured in such cases?

For austenitic materials, stud diameters of more than 16 mm are recommended as well as welding under shielding gas. This leads to a considerable reduction of splashes and plunge impediments. In the course of an extensive test series carried out for a large company active in the nuclear sector, shear connectors with diameters of 16, 19 and 22 mm were welded onto plates with thicknesses of 10, 20 and 30 mm, and at various distances from the edges down to a minimum of 20 mm (**Fig. 12**). The actions to compensate the blowing effect are basi-

Fig. 8: Flawless result on small anchor plate (© Trillmich)

Fig. 9: Flawless result even on the corner of a plate (© Trillmich)

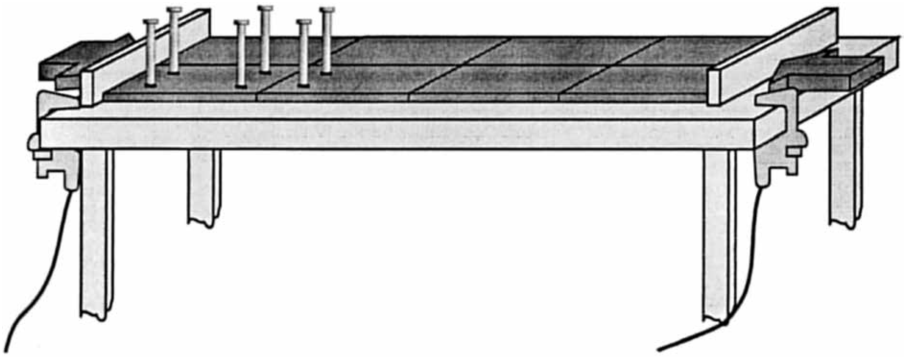

Fig. 10: Suggestion from specialist literature for compensation of the blowing effect (© [3])

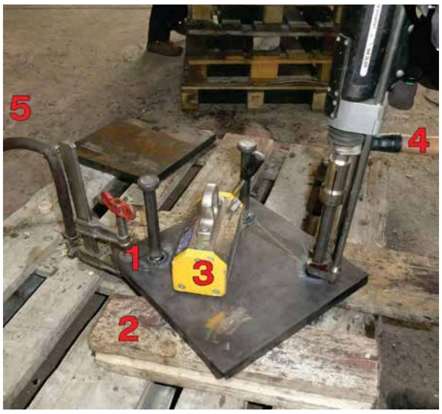

Fig. 11: Recommendation for successful shear connector welding on anchor plates (© Trillmich)

Fig. 12: Stainless steel anchor plates for the nuclear sector (© Trillmich)

cally the same as with ferritic workpieces, but the effects of the individual components were significantly different.

For shear connectors 22 mm in diameter, the necessary balancing mass proved to be so large that reproducible as well as economically feasible production was hardly possible (**Fig. 13**). This is why the traditional process of welding between two ground clamps was chosen in that case (**Fig. 14**). With ferritic workpieces, welding immediately beside a ground clamp is never successful, even with a second ground clamp further away, since the welding current naturally takes the shortest way to the clamp. There was hardly any space available for mounting a ground clamp, yet the welding result was impeccable (**Fig. 15**), as shown by the macro section in **Fig.16**.

With about 200 shear connectors welded under the conditions described above, the rate of non-compliant welding results was significantly below 5 %. The assessment was based on a visual check according to EN ISO 14555, which was verified by random tensile tests and macro sections.

Fig. 13: Unsuccessful compensation attempts on stainless steel plates (© Trillmich)

Fig. 14: Successful compensation only with two ground clamps (© Trillmich)

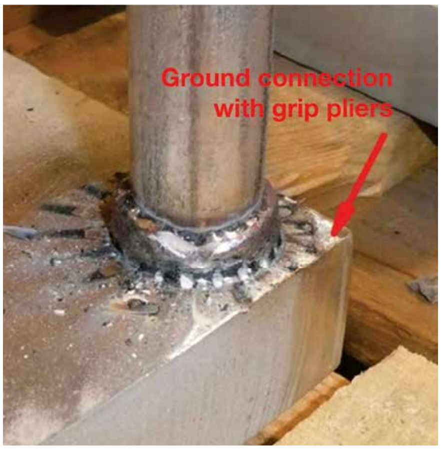

Fig. 15: Flawless result very close to the corner of the plate (© Trillmich)

Advantages of complete monitoring

In series production with modern stud welding equipment, complete monitoring of the entire welding process is of great advantage. Here, all relevant data, such as welding current, welding time, arc voltage, as well as lift, plunge depth and plunge speed are available for documentation and evaluation. Destructive tests can thus be minimized. The values of welding current, welding time, lift (length of the arc) and protrusion (plunge depth) must lie verifiably within certain limit values, only then can the visual check of welded studs provide security. However, the assessment of process parameters in a weld must always be holistic (with consideration of all contributing factors). To a certain extent, a lower value for one parameter, e.g. current, can be compensated by a longer welding time.

It is vital to have the stud movement – a decisive factor in welding – measured by a displacement measurement system. If this movement is not precisely coordinated with the "current program", this may cause what is known as a cold plunge. If the stud is not united with the workpiece during the phase of the drawn arc, but thereafter, even no more than milliseconds later, an oxide skin will immediately form on the melt, since it is no longer protected by metal vapour.

More or less sizeable lacks of fusion will be the consequence. As these invariably develop first around the edge, they have the effect of a predetermined breaking point and lead to a drastic reduction in load capacity even with a low proportion of the surface area. These defects cannot be detected by visual examination! Therefore, the recording of only current and time in conventional stud welding equipment creates a false illusion of safety.

Cold plunges can be caused by a damping effect set too high, by friction between the stud and the ceramic ferrule, by splashes solidifying between the stud and the ceramic ferrule during welding or by malfunctions of the gun. Some causes can be recognized during the simplified work inspection before the start of the shift [1], but others cannot, because they occur only sporadically. Definite proof that both welding pools have been united within the arc burning phase can be furnished by measurement of the short circuit time.

As mentioned before, stud welding is an automatic welding process characterized by the fact that the operator can neither intervene nor compensate any irregularities during the process. Any deviations from the set values can therefore only be recorded by measurement systems.

Table 1 shows an example of complete recording of all relevant parameters. In the bottom line, a weld with a "cold

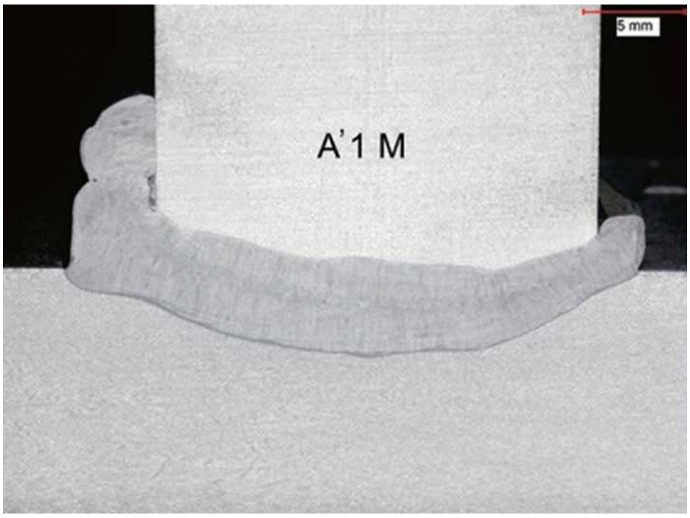

Fig. 16: Macro section of a flawless stud weld (© Trillmich)

Fig. 17: Failure of the bend test in spite of passing the visual check (© Trillmich)

plunge" is depicted, recognizable by the short circuit time of 0 milliseconds.

A stud that is very unevenly melted due to a blowing effect falls short of the normal plunge depth, which the displacement measuring system registers, while preventing further welds if set to do so (**Table 2**). For in most cases, the operator would not immediately notice the incomplete weld collar in series welds, because he removes the ceramic ferrules only at some time later. So, process monitoring prevents long series of faulty welds. Even where no measurement data memory is connected, the actual values of every weld can be read out directly from the power source, and the continuation of welding can be stopped in case of irregularities.

Verifiable safety for high-quality welds

The production of anchor plates with welded-on shear connectors requires

Table 1: Recording and monitoring of welding parameters

No.	Date	Time	Gun No.	Welding time (ms)	Welding current (A)	Arc voltage (V)	Plunge speed (mm/s)	Lift (mm)	Plunge depth (mm)	Protrusion (mm)	Short circuit time (ms)
133	10.10.23	15:10:13	1	1248/0 0/-0	1890/0 0,0/0,0	31,4/0,0 0,0/0,0	60/0 0/-0	4,4 : 0,0 0,0 : -0,0	4,2 : 0,0 0,0 : -0,0	4,3 : 0,0 0,0 : -0,0	27/0 0,0/0,0
134	10.10.23	15:28:58	1	1249/0 0/-0	1890/0 0,0/0,0	29,7/0,0 0,0/0,0	52/0 0/-0	4,4 : 0,0 0,0 : -0,0	4,3 : 0,0 0,0 : -0,0	4,3 : 0,0 0,0 : -0,0	48/0 0,0/0,0
135	10.10.23	15:31:26	1	1249/0 0/-0	1890/0 0,0/0,0	30,3/0,0 0,0/0,0	60/0 0/-0	4,4 : 0,0 0,0 : -0,0	4,3 : 0,0 0,0 : -0,0	4,4 : 0,0 0,0 : -0,0	25/0 0,0/0,0
136	10.10.23	15:32:21	1	1249/0 0/-0	1890/0 0,0/0,0	30,8/0,0 0,0/0,0	62/0 0/-0	4,5 : 0,0 0,0 : -0,0	3,9 : 0,0 0,0 : -0,0	4,0 : 0,0 0,0 : -0,0	28/0 0,0/0,0
137	10.10.23	15:33:12	1	1249/0 0/-0	1889/0 0,0/0,0	30,4/0,0 0,0/0,0	61/0 0/-0	4,5 : 0,0 0,0 : -0,0	4,1 : 0,0 0,0 : -0,0	4,2 : 0,0 0,0 : -0,0	28/0 0,0/0,0
138	10.10.23	15:34:48	1	1248/0 0/-0	1890/0 0,0/0,0	30,9/0,0 0,0/0,0	61/0 0/-0	4,4 : 0,0 0,0 : -0,0	4,7 : 0,0 0,0 : -0,0	4,7 : 0,0 0,0 : -0,0	19/0 0,0/0,0
	cold plunged			903/0 0/-0	1551/0 0,0/0,0	34,0/0,0 0,0/0,0	50/0 0/-0	3,6 : 0,0 0,0 : -0,0	2,2 : 0,0 0,0 : -0,0	4,9 : 0,0 0,0 : -0,0	0/0 0,0/0,0

Table 2: Excerpt from the values table of a weld with too small plunge depth

Gun	tw	Iw	U	vpm	L	pd	P	tK
1	1139/1139	2023/1999	37,3/36,3	90/103	5,2 : 5,0	4,6 : 5,2	6,1 : 5,3	35/32
	4/-4	3,0/-3,0	5,0/-5,0	30/-30	0,5 : -0,5	1,0 : -0,5	1,5 : -1,5	30,0/-30,0

particular precautions to achieve repeatably flawless results. Stud welding is an automatic welding process which runs program-controlled, but requires from welding supervisors and operators that they provide the necessary prerequisites for perfect results prior to starting the welding process. The attachment of ground clamps and balancing masses adapted to the welding job, as well as the correct alignment of the welding gun, are such prerequisites.

Modern inverter stud welding appliances with current and movement monitoring not only offer excellent welding properties, but are also able to save and evaluate the actual values. Furthermore, they provide the option to lock the device in the event of any results outside the process window and to inspect the resulting weld. In conjunction with the compulsory visual check, the system ensures verifiable safety and has thus set new benchmarks in terms of requirements for high-quality stud welds. ■

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