Journal for Technology of Plasticity, Vol. 27 (2002), Number 1-2

JOINING BY FORMING - NEWER DEVELOPMENTS

Voelkner, W.; Jesche, F; Lachmann, L.
Fraunhofer Institute for Machine Tools and Forming Technologies, Chemnitz/Dresden

ABSTRACTS

Newer joining techniques by forming are introduced in this contribution. They increasingly substitute the conventional welding techniques which are often not suitable caused by heating of material. High strength material sensitively reacts to the temperature with a loss of fatigue strength. Moreover the sheet metals are often coated with organic protective layers, which e.g. are not electrical conductive. In this case joining by forming avoids these disadvantages and in dependence of the requirements the various techniques can be used like clinching, self-pierce riveting with semi tubular rivet or solid rivet. The most simple and cheapest technique is clinching. It based on dot-shaped embossing and extrusion of the joining parts. In case of self-pierce riveting with semi tubular rivet the joining parts are jointed by piercing the upper sheet metal with the rivet and by spread forming of the hollow part of the rivet in the lower metal sheet. In case of self-pierce riveting with a solid rivet both of joining parts are pierced by the solid rivet. After it material is pressed in a circular groove at the lower part of the rivet. The rivet is not plastically formed.
In all cases one gets an undercut and a force-fit interconnection.

1 INTRODUCTION

The substitutions of conventional welding techniques like e.g. resistance spot welding by mechanical joining especially for car bodies is increasing. The reasons are the greater loss of lifetime caused by the local heating of the high strength steel and the thermal damages of protective layers in case of resistance spot welding. Alternative techniques are such like clinching or self-pierce riveting with semi tubular rivet or with solid rivet. The development is not concluded, in so far as there are steadily further developments.

2 JOINING BY FORMING (SELECTED EXAMPLES)

2.1 Introduced techniques

2.1.1 Clinching (Fig. 1)

There are exist numerous variants, which are different by the share of shearing, the number of process steps or by the kind of the female die, if it is parted or not parted. The most simple technique is made only in one step without shearing and with a solid die.

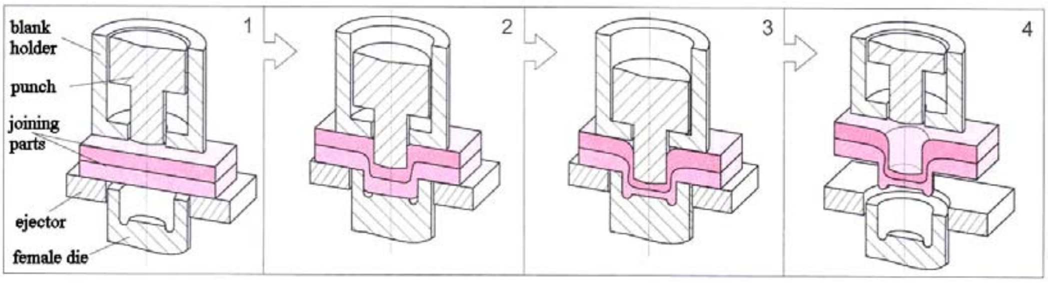


Fig. 1: Clinching without share of shearing in one step [1]

The joining parts are layed on the female die and are fixed by the blankholder. The punch shear forms a local material portion relative to the neighbouring material portions to create a raised pattern in the surface without changing the material thickness.
In a continuous process the local raised pattern is pressed in the cavity of the female die, in which the material thickness is reduced and extruded, on this way an undercut between the two joining parts and force-fit interconnection is generated.
The return movement follows, when the necessary force or the wanted way is reached.

2.1.2 Self-pierce riveting

These techniques does happen without pre-piercing before riveting, but in this case piercing is executed by the rivets. One differs in self-pierce riveting with semi tubular rivets and with solid rivets.

2.1.2.1 Self-pierce riveting with semi tubular rivet (Fig. 2)

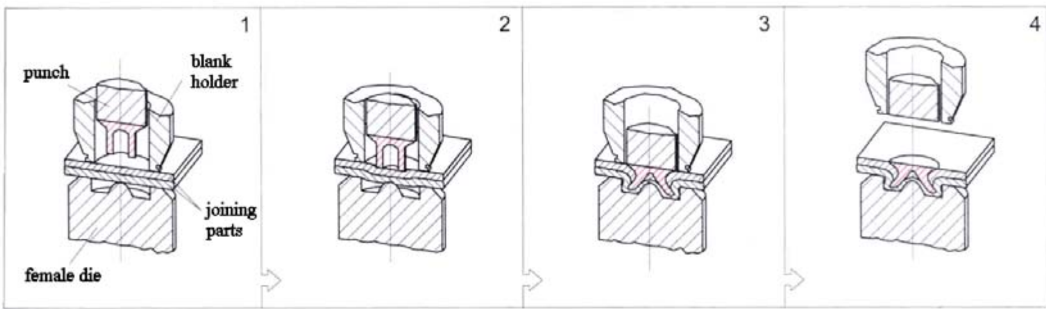


Fig. 2: Self-pierce riveting with semi tubular rivet [1]

The procedure is as follows:
The joining parts are fixed between the female die and the blank holder.
After feeding the rivet the axial movement of the punch caused, that the rivet the upper sheet metal pierces and the slug is stored in the cavity of the rivet.
The further penetration of the rivet in the lower sheet metal caused a spread forming of the hollow part of the rivet in it and a generating of a closed head in the female die.
The return movement follows, when the required force or the wanted way is reached.

2.1.2.2 Self-pierce riveting with solid rivet (Fig. 3)

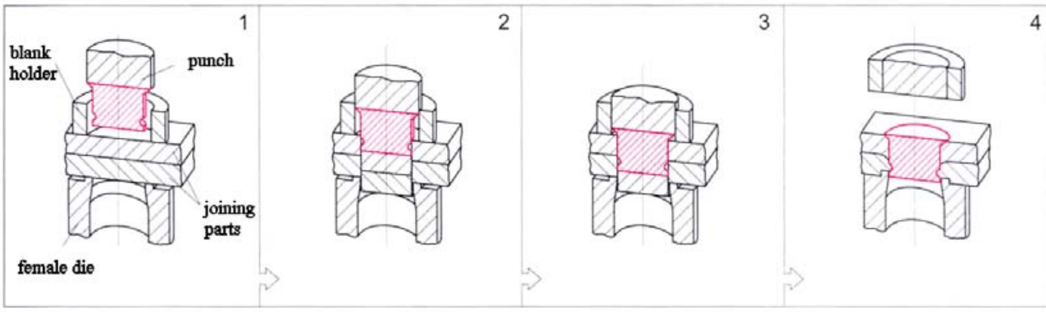


Fig. 3: Principle of self-pierce riveting with solid rivet

Similar like at the above mentioned techniques the joining parts are fixed between the female die and the blankholder.
After feeding the rivet the axial movement of the punch caused, that the rivet pierces the both of the joining parts and ejects the slugs.
After it the punch force presses a circular groove in the lower sheet metal by a ring shaped counterpunch (female die). The displaced material penetrates in a ring groove at the lower part of the rivet. On this way an undercut and force-fit interconnection is produced. The solid rivet is not plastically formed in opposite to the semi tubular rivet. The return movement follows like at the other techniques.
A comparison between self-pierce riveting and resistance spot welding is given in Fig. 4.

criteria of applic 	Self-pierce riveting	resistance spot welding
kind of connection	mechanical, no heat transfer, connecting by shape and force	melting, heat transfer, connecting by material
various materials	possible	only with bimetal
nonmetallic material	possible	impossible
coated material	possible	in general impossible
optical view	inconvenient	better
thickness of material	dependent on the technique St s = 6 mm (total) Al s = 11 mm (total)	with 60 kA up to ca. 4 mm
static strength	less	higher
cycle strength	higher	less
lifetime of dies	100.000 - 200.000 joinings	2.500 points

joining per min	max. 20 - 60	20 - 40
installation	hydraulic pneumatic	compressed air + current + water
consumption of energy	less	more
demand of area	less	more
cost of investment	less	more

Fig. 4: Comparison between self-pierce riveting and resistance spot welding [2]

2.2 Numerical simulation

The theoretical description of the above presented techniques is not easy. The forming process is hardly describable with elementary methods caused by the geometrical and material specialities. Normaly the prediction of the behaviour of the joint under loading is more important than the process of joining. But the knowledge of generating of an undercut and force-fit interconnection during the procedure of joining is an important assumption for the prediction of the shear-tension and the peel strength. The real type of stressing is a combined stressing of both shares. There are existing at least two resp. three parts - often in geometry and material differing - which are plastically deformed. Therefore only the FEM is a suitable instrument. Some selected examples are demonstrated.

2.2.1 Clinching [3]

In Fig. 5 the moving away of the material in the groove of the female die and the belonging main stresses in dependence of the punch way are shown.

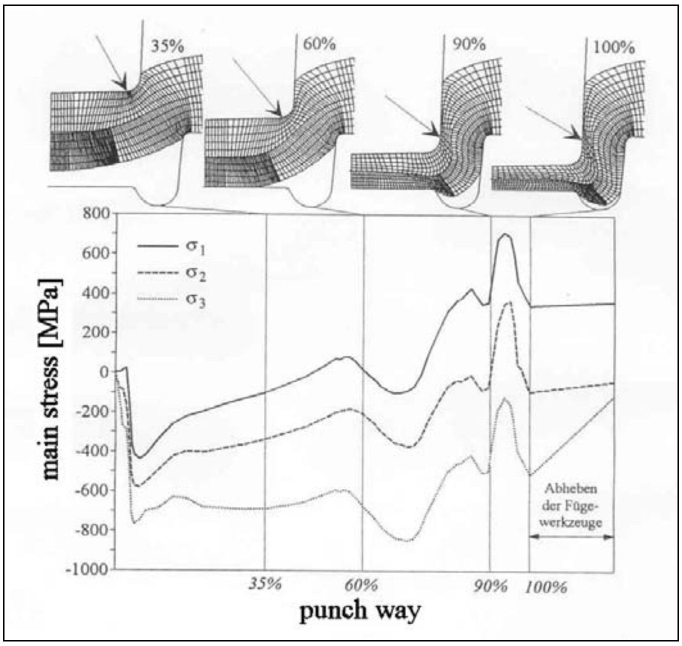


Fig. 5: State of main stresses in dependence on the punch travel in a ring element (s. pointer)

In Fig. 6 the effective strain of the marked elements is demonstrated. The behaviour of forces and deformations determined with FEM coincited with the experimental results in a close tolerance. ABAQUS was used as the FE-system.

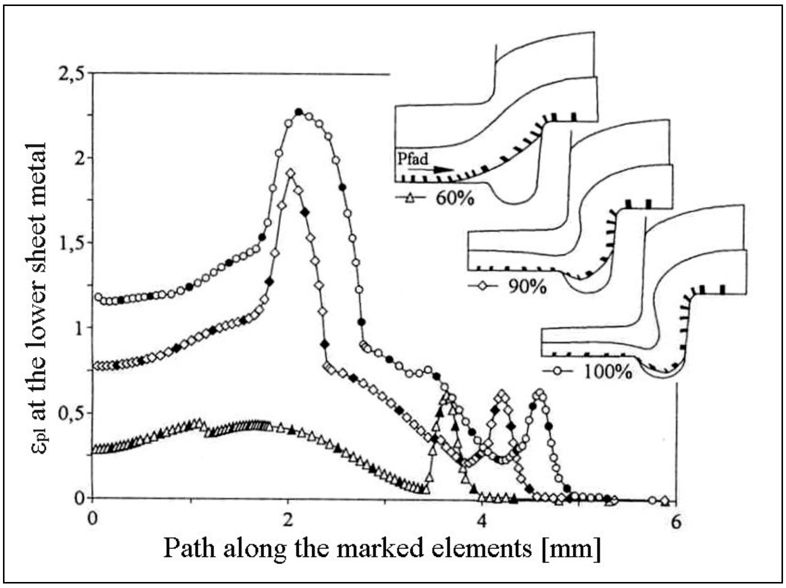


Fig. 6: Effective strains of the marked elements along the surface of the lower sheet metal

2.2.2 Self-pierce riveting with semi tubular rivet [4]

In one of the latest researching projects the numerical simulation of the above mentioned technique was carried out with the FE-system MSC.Autoforge. In Fig. 7 a comparison between the experimental results (left) and the numerical simulation (right) is shown. Various steps of the joining procedure are demonstrated. The accordance is very well regarding the more complicated plastically process with shearing and deforming of the upper sheet, the spreading of the semi tubular rivet in the lower sheet by generating of a closed head.

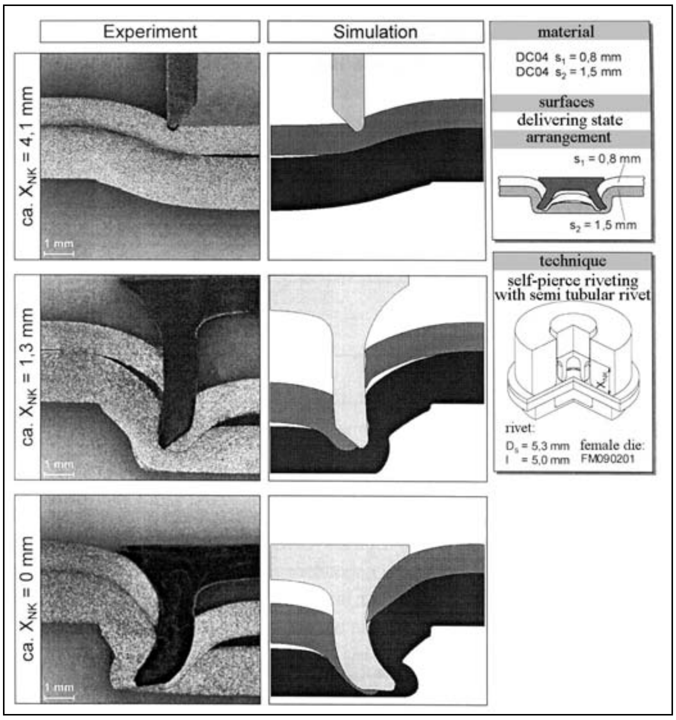


Fig. 7: Comparison of experimental and computed results for various steps (material: DC04)

In Fig. 8 the force-way-behaviour is shown in comparison with the experimental result and the theory with a similar good accordance like above.

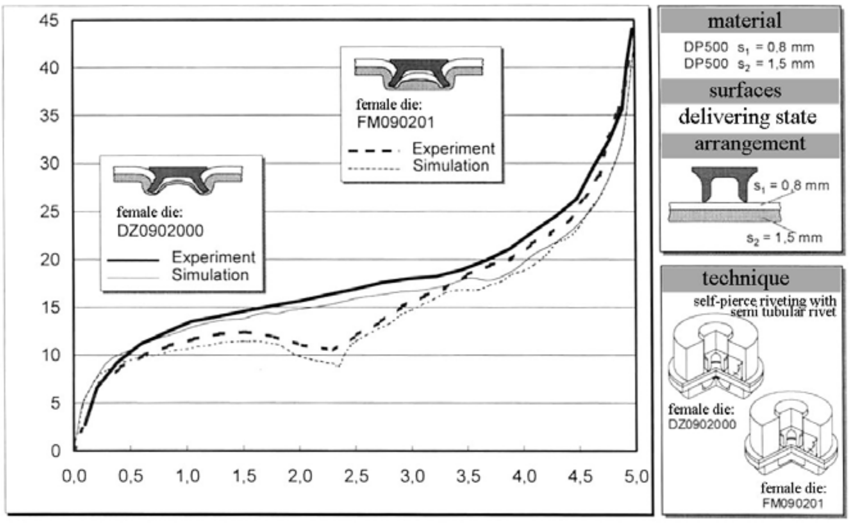


Fig. 8: Comparison of the experimental and computer results of the force-displacement-behaviour (material DP500)

2.2.3 Self-pierce riveting with solid rivet [5]

The numerical simulation was done with the FE-system DEFORM. In this case the rivet remains plastically undeformed, it is only elastically stressed. In Fig. 9 one can see, that at first the both sheets are pierced by the rivet as a punch. After piercing a ring-shaped punch presses sheet material from below in the circular groove of the rivet.

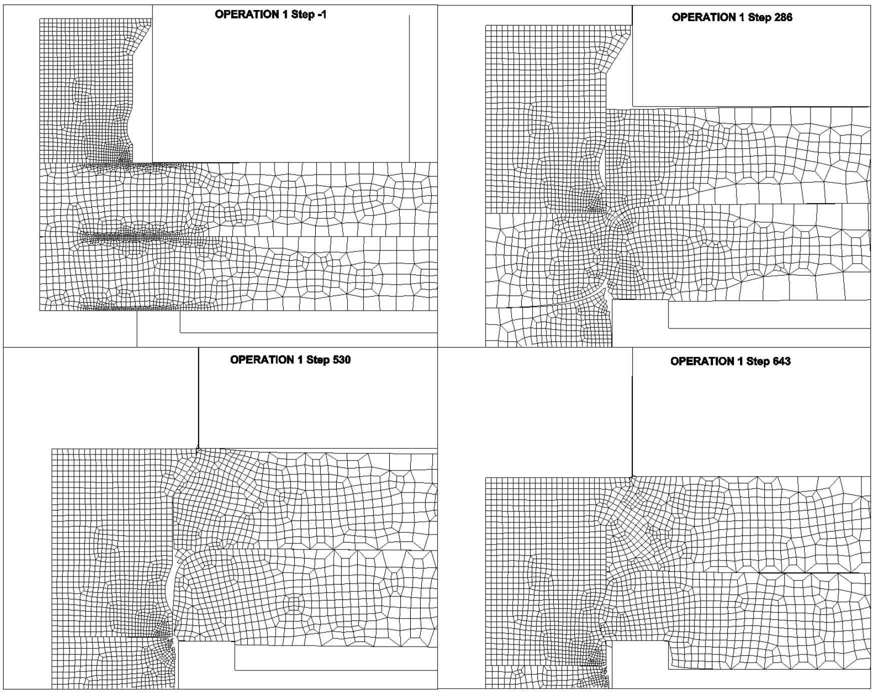


Fig. 9: Selected steps of shearing and deformation in case of pierce riveting with solid rivet

In Fig. 10 a comparison between experimental (left) and theoretical (right) results is shown. One can see a good accordance between the two results. Moreover is recognizable, that the distribution of the radial stresses is different at the interface between rivet and sheet metal. It is demonstrated by a varied couloring from white to black. In the white zones there are less contact between rivet and joining part. If one would zoom the mesh at the transition point of the coneshaped head of the rivet to the cylindrical shank you can see there is no contact with the sheet metal. Moreover it was verificated by neurodiffractometric examination. In this zone the radial stresses are zero.

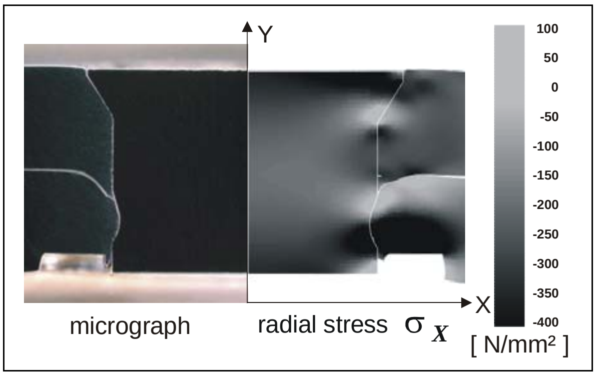


Fig. 10: Comparison of experimental and computed results (material: DC 04)

In Fig. 11 is shown the behaviour of the radial, axial and circumferential stresses in a plane perpendicular to the axis of the rivet in the region of the cylindrical shank. The buckling course of the curves is caused by an effect of the coneshaped head of the rivet.

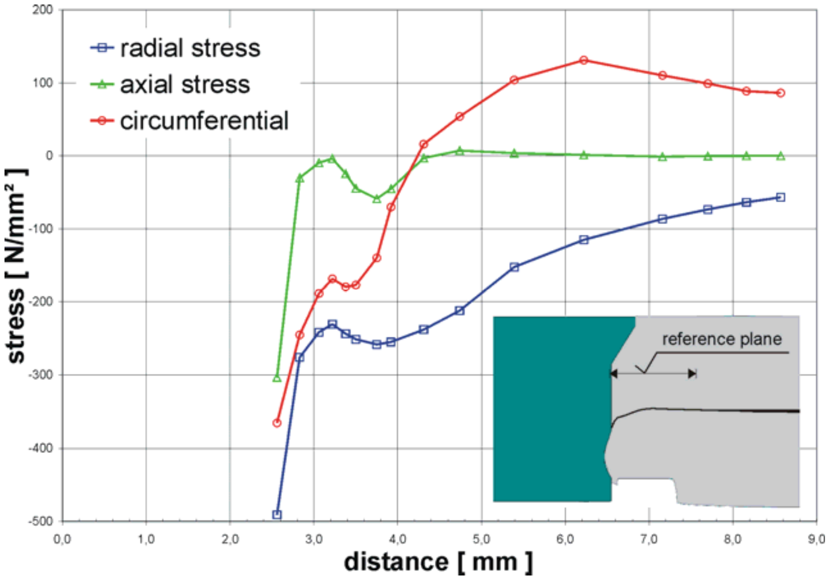
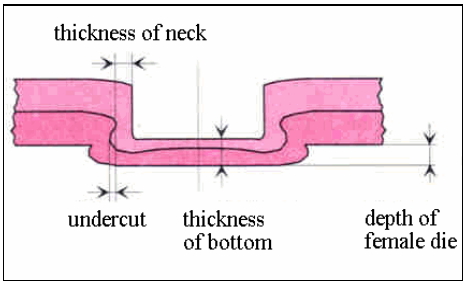


Fig. 11: Distribution of radial, axial and circumferential stresses in the marked plane

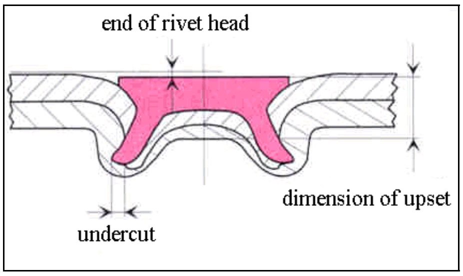
2.3 Strength properties

Clinching and self-pierce riveting are in competition with resistance spot welding. An estimation of the joining quality does happen by the measuring of the essential geometry dimensions. Therefore a destructive testing method is necessary by making a micro-section. In case of clinching the strength is determined by the dimensions of undercut and the thickness of the neck (a). These dimensions are dependent on the dimensions of the depth of the female die, the diameter of the punch and the female die as well as on the thickness of the bottom. In case of self-pierce riveting with semi tubular and solid rivet the strength esp. the peel tension strength is dependent on the dimension of undercut (b and c).

a) clinching



b) self-piercing riveting with semi tubular rivet



c) self-piercing riveting with solid rivet

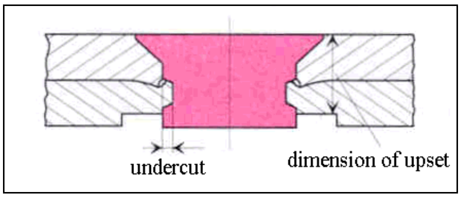
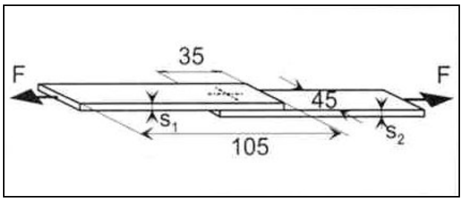


Fig. 12: Essential geometry dimensions of the various joining points [1]

a) shear tension strength



b) peel tension strength

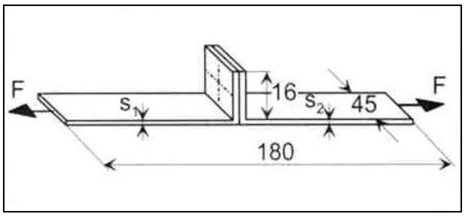


Fig. 13: Specimen for static testing [1]

Another estimation of the joining quality is the determination of the static shear tension strength and the peel tension strength. The used specimen for determination are demonstrated in Fig. 13. They are not standardized up to now, but they are comparable with the specimen for resistance spot welding. By means of these specimen the quasi static maximum force F_m and the stretching force F_s are determined (Fig. 14).

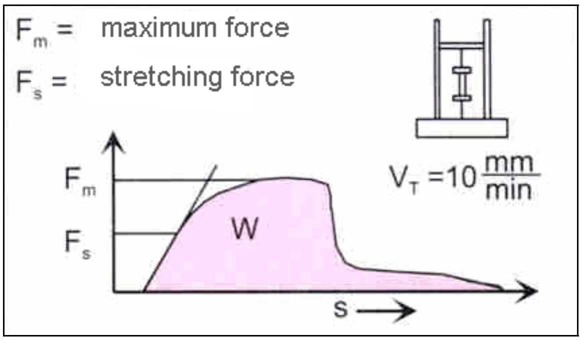


Fig. 14: Force-displacement behaviour

A comparison of the various techniques with high strength steel ZStE 340 is demonstrated in Fig. 15. The joint by resistance spot welding shows a higher shear tension and peel tension strength in opposite to the other techniques. The values of the other techniques are lower. The simpliest technique of clinching shows the lowest values.

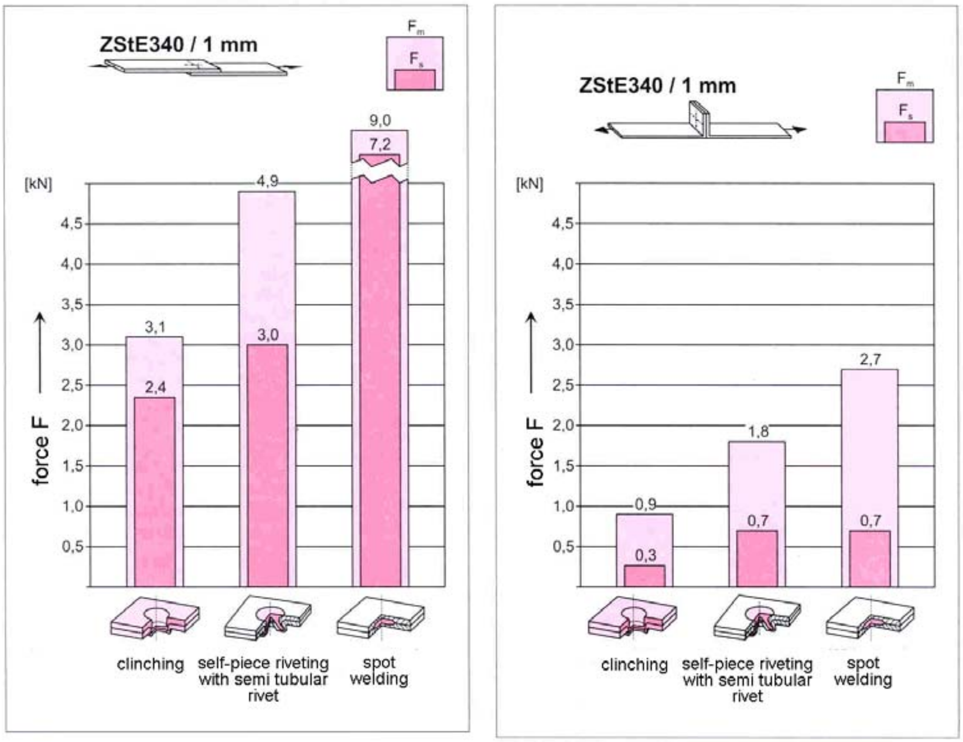
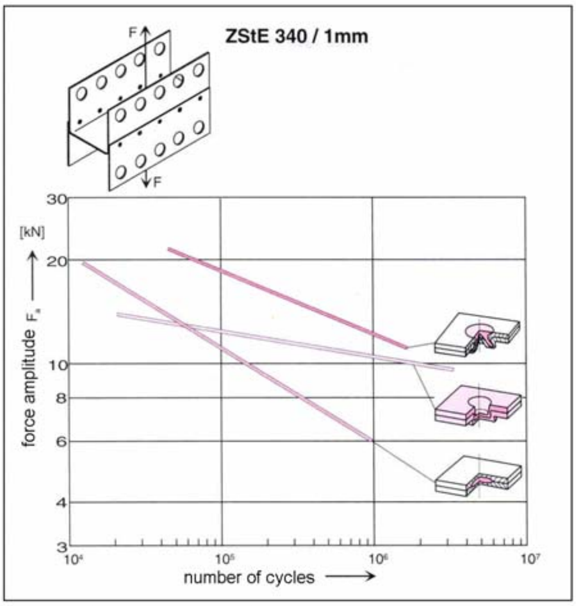
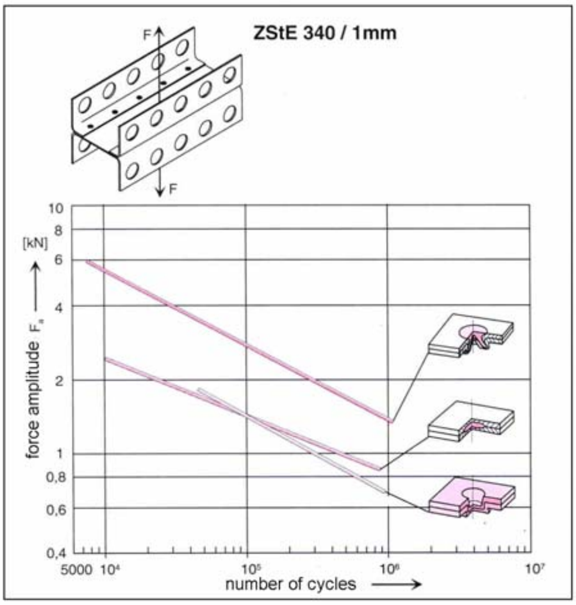


Fig. 15: Test results under quasi static conditions [1]

But this static behaviour is not valid for cyclic loading like shown in Fig. 16a and Fig. 16b. In this case the fatigue limits of the techniques by forming deliver higher values in comparison with resistance spot welding. On this way the capacity of the high strength steel is utilizable. Although the formed joints are very sensitive against peel loading the results are better than as resistance spot welding.



a) shear tension fatigue limit



b) peel tension fatigue limit

Fig. 16: a) shear tension fatigue limit
b) peel tension fatigue limit

3 CONCLUSION AND OUTLOOK

In the contribution some techniques of joining by forming are introduced. The application is increasing caused by avoiding the heating of joining parts. Today it is necessary in connection with numerous high strength materials, which would loss strength, if they would heated. There are presented 3 different techniques like clinching and self-pierce riveting with semi tubular rivet and with solid rivet. Clinching is the most simple technique, but accompanied of less joining strength. The self-pierce riveting with semi tubular rivet is the method with the greatest joining strength, but not the cheapest amongst the conventional techniques. In general the advantages are: no thermal loading and thermal deformation, joining of different materials (e.g. steel and aluminum), higher fatigue strength, less damage of surface, easy to handle. The disadvantages are: the high setting force, limited thickness, mechanical distortion, no reliable prediction of strength behaviour without extensive and expensive experiments. The targets in the future will be: numerical simulation of the process, reduction of experiments and tests, further development of available techniques and new development of techniques for joining by forming.

4 REFERENCES

[1] Hahn, O.; Klemens, U.
Fügen durch Umformen, Nieten und Durchsetzfügen - Innovative Verbindungsverfahren für die Praxis
Studiengesellschaft Stahlanwendung, Dokumentation 707, 1996, Düsseldorf

[2] Voelkner, W.
Present and future developments of metal forming: selected examples
Journal of Materials Processing Technologies, 106 (2000) 236 - 242

[3] Klasfauseweh, U.
Beitrag zur Simulation nichtschneidender Durchsetzfügevorgänge
Dr.-Ing. Diss., Univ. Paderborn 1994

[4] Dölle, N. J.
Numerische Simulation des Fügeprozesses beim Stanznieten mit Halbhohlniet von duktilen Blechwerkstoffen
Dr.-Ing. Diss., Univ. Paderborn, 2000

[5] Jesche, F.
Unveröffentlichtes Manuskript
Fraunhofer Institut für Werkzeugmaschinen und Umformtechnik, Chemnitz/Dresden, 2002

NOVIJI RAZVOJ SPAJANJA DEFORMISANJEM

Voelkner, W.; Jesche, F; Lachmann, L.

REZIME

U ovom radu predstavljene su nove metode spajanja deformisanjem. Ove metode u sve većoj meri substituišu konvencionalno zavarivanje, čiji je osnovni nedostatak zagrevanje materijala.
Materijali sa visokim mehaničkim osobinama posebno su osetljivi na povišene temperature u tom smislu da u značajnoj meri pri tome gube dinamičku čvrstoću. Sa druge strane, limeni delovi su često presvučeni organskim zaštitnim slojevima koji nisu provodnici, što takođe limitira primenu zavarivanja. Primenom spajanja deformisanjem ovi problemi se prevazilaze.
Nekoliko najčešće primenjivanih metoda spajanja deformisanjem prikazano je u ovom radu.
Takođe su dati i komparativni primeri: spajanje deformisanjem – zavarivanje.
Prikazani procesi su analizirani i FEM simulacijom (ABAQUS). Tom prilikom određeno je naponsko stanje u elementima koji su međusobno spojeni, efektivne deformacije kao i potrebne sile.
Teoretski dobijeni rezultati verifikovani su eksperimentom. Zaključno se može reći da su glavne prednosti spajanja deformisanjem sledeće:

- nema termičkih opterećenja
- mogućnost povezivanja različitih materijala
- veća dinamička čvrstoća
- laka izvedba i rukovanje

Nedostaci su:

- potrebna mehanička sila
- ograničena debljina lima koji se međusobno spajaju

Za očekivati je da se ova vrsta spajanja i dalje veoma uspešno razvija i primenjuje.