Factors Influencing the Strength of Mechanical Clinching

Remo Pedreschi

Braj Sinha

Russell Davies

Rory Lennon

Fourteenth International Specialty Conference on Cold-Formed Steel Structures
St. Louis, Missouri U.S.A., October 15-16, 1998

Factors Influencing the Strength of mechanical clinching

by
Remo Pedreschi[1], Braj Sinha[2], Russell Davies[3] and Rory Lennon[4]

Summary

The influence of material strength and thickness, direction of load, multi-layer connections and dis-similar thicknesses of steel on the strength of mechanical clinching is considered. Expressions to predict the strength of mechanical clinching are presented.

[1]Dr Remo Pedreschi, Senior Lecturer
Department of Architecture, University of Edinburgh
[2]Dr Braj Sinha, Reader
Department of Civil Engineering, University of Edinburgh
[3]Dr Russell Davies, Engineer
Elliot and Co Structural Engineers
[4]Rory Lennon, Research Associate
Department of Architecture, University of Edinburgh

Factors Influencing the Strength of mechanical clinching

by
Remo Pedreschi[1], Braj Sinha[2], Russell Davies[3] and Rory Lennon[4]

Abstract

The use of cold-formed steel in fabricated structures is increasing. A major factor in the efficiency and economics of fabricated cold-formed steel structures is the nature and design of the connections. Mechanical clinching, also known as press joining, uses the parent metal of the sections to form a structural connection and has advantages over conventional connection techniques. The paper describes the key characteristics of mechanical clinching, illustrated using some typical, practical applications. The strength of the connection is influenced by a number of factors which include: Ultimate tensile strength, thickness of steel, number of layers of steel connected and where, dis-similar layers of steel are connected, the pattern of lay-up of the steel in relation to the joining tools.

Introduction:

During the last two or three years there has been a rapid increase in the use of cold-formed steel in residential applications. Builders are replacing traditional timber studs with cold formed steel C sections in the construction of both stud wall panels and roof trusses. Dedolph and Jaselkis (1997) attribute this change to the following:

- A general decline in the quality of timber
- Fluctuating timber prices
- Limited reusability of timber studs.

The nature of steel production and supply tends to avoid these problems and hence becomes a more attractive alternative to the contractor. The transition from timber to steel does not seem to present great difficulties to the carpenter. Appropriate documentation on the structural design and construction of steel stud framing is becoming available with the publication of the Prescriptive Method for Residential Buildings (NAHB 1996).
A key factor in the efficient fabrication of cold-formed steel structures is the type of connection used.

Self tapping screws are most often specified for site assembled stud frames and their design and application is covered in the Prescriptive Method. Other forms of connection such as rivets, bolts and welding are also used, mostly in pre-engineered stud frames.

Conventional techniques such as these have disadvantages which may contribute to the overall inefficiency in the fabrication process

- rivets and self tapping screws are sensitive to operator error and require accurate fit of the components before installation.
- the strength of bolted connections is generally governed by bearing failure in the relatively thin cold-formed sections and therefore the bolt is never used to its full capacity.

[1] Dr Remo Pedreschi, Senior Lecturer
Department of Architecture, University of Edinburgh
[2] Dr Braj Sinha, Reader
Department of Civil Engineering, University of Edinburgh
[3] Dr Russell Davies, Engineer
Elliot and Co Structural Engineers
[4] Rory Lennon, Research Associate
Department of Architecture, University of Edinburgh

- welding destroys galvanised steel coatings, producing fumes and by-products which may contaminate welds and also requires skilled labour

Mechanical clinching techniques have been used in general manufacturing processes, such as automobiles and air conditioning for a number of years. These techniques offer a number of potential benefits over the conventional methods for cold-formed steel structures that are likely to lead to improved fabrication efficiency. There are a few variations in the detailed configurations of mechanical clinching, also known as press-joining, but the key aspects are the use of pressure and controlled cutting and deformation to push one layer of steel through another and form a strong mechanical clinch between the steel layers. The process of forming a press join is illustrated in figure 1 and described in more detail elsewhere (Pedreschi et al 1996) and (Davies 1996). The advantages offered by these methods over conventional techniques can be summarised as follows:

- galvanised and painted coatings are left intact.
- the process uses very little energy, approximately 10 percent of an equivalent spot weld.
- the process can be readily automated
- it requires only semi-skilled operatives
- it uses only the parent metal of the elements to be connected and therefore eliminates the need for consumables such as screws or rivets.
- it can be easily checked for quality by non-destructive methods.

Mechanical clinching is now being used in buildings in a number of different applications. Figure 2 illustrates the use of press joining in a fabricated steel truss. The truss is manufactured off site and uses a semi automatic production process for all the node point connections.
Figure 3 shows the use of mechanical clinching to produce a more efficient form of steel stud with closed triangular boxed flanges. Clinching is applied during the roll-forming process.
Figure 4 illustrates a fabricated beam which uses clinching to connect the flange to the web.The beam can span upto 50 feet (15 metres). The web uses 0.039 ins (1.0 mm) thick steel whilst the flange uses 0.078 ins (2.0 mm) thick steel. Tests have been carried out on depths of the beam between 11.8 and 23.6 ins (300 and 600 mm). To date most applications of press joining have concentrated on factory produced elements however at least two tool makers have developed small tools specifically intended for in the field fabrication of steel stud frames, figure 5.
The original applications of press joins were essentially either non-structural or semi-structural and consequentially the attention of earlier researchers such as Leibig (1987)and Bober (1987) and others was focused on production parameters rather than a detailed understanding of the structural behaviour of the press joins. Understanding the structural behaviour and the development of predictive methods for calculating the strength of press joins are essential for the further application of the technique. There is an ongoing programme of research into the structural behaviour of mechanical clinching in cold-formed steel structures at Edinburgh University, details of this research have been reported elsewhere (Pedreschi et al, 1996, Davies et al,1996, Davies 1996). This paper discusses the some key factors that influence the strength of mechanical clinching in cold formed steel structures. These include:

- steel strength, thickness and orientation of applied shear
- multi-layer joints
- dis-similar thicknesses
- variability of press join strength

Although considerable progress has been made in understanding the structural behaviour of mechanical clinching there are areas where further research is in progress or needed and these are identified.

Steel strength, thickness and orientation of applied shear

The most common form of connection is between two layers of steel of the same thickness and ultimate tensile strength. A considerable amount of research has been carried out on this particular arrangement and has been reported elsewhere, (Davies et al 1996, and Davies 1996). This work has shown, as would be expected, that the shear strength of the connection increases as the ultimate tensile strength and thickness of the steel increases. The most typical form of press join, figure 6, displays orthotropic behaviour and the strength is significantly influenced by the orientation of the applied shear to the connection itself. The normal convention for defining the angle of shear to the orientation of the connection is also shown in figure 6. As the angle changes from 0 to 90 degrees there is a progressive reduction in shear strength. The mode of failure changes as the angle of applied shear changes. When the direction of applied shear is 0 degrees failure occurs by shearing across the two protruding parts of the punch side layer as they pass through the die side layer. When load the load is applied at 90 degrees failure occurs by deformation of the punch side steel leading to tearing and eventual pull-out from the enclosing die side layer. Typical results showing the influence of angle of applied shear are presented in figure 7. Various expressions have been developed to predict the shear strength of press joins taking into account the influence of ultimate tensile strength (UTS), thickness and angle of applied shear. These are reviewed in more detailed elsewhere (Davies 1996). Recent work by (Pedreschi et al 1998), reviewing results of a number of researchers and combining these results with the research carried out at Edinburgh University has shown that there is consistent behaviour across all the available data that indicates a linear relationship between shear strength, UTS, steel thickness and angle of applied shear. The following expression was shown to provide an accurate prediction of the shear strength of press joins for two layers of steel with equal thickness and steel strength.

$$F_{p2} = (0.25 - 0.00086 \, . \, Ø) \text{ UTS} \, . \, t \text{ for } 0 \le Ø \le 90 \qquad \text{equation 1}$$

where UTS and t are in psi and inches.

$$(F_{p2} = (6.34 - 0.022 \, . \, Ø) \, . \, \text{UTS} \, . \, t \quad (\text{UTS in N/mm}^2 \text{ and t in mm}))$$

Equation 1 is based on over 140 tests results covering a broad range of materials including thicknesses ranging from 0.0236 - 0.0787 ins, (0.6 - 2.0 mm) and ultimate tensile strengths ranging from 640287-99280 psi, (280 - 690 N/mm^2). Figure 8 compares the predicted and experimental results and good agreement can be seen. A statistical analysis of the results (Pedreschi et al 1998) indicated that over 80 % of the predicted results were within 15% of their corresponding test result.

Multi-layer connections

In the design of some structural systems advantages can be obtained by connecting through more than two layers of steel. The trusses shown in figure 2 incorporate a triangular shaped closed section. This is made possible by the simultaneous clinching of four layers of steel. Research into this particular form of connection (Pedreschi and Sinha 1997) has shown that the same basic relationships between UTS, steel thickness and angle of applied shear, previously demonstrated in two layer joints, also apply in multi-layer connections. The results are presented graphically in figure 9.
An expression for predicting the shear strength of the connections was developed and it can be it can be seen that it takes the same form as equation 1.

$$F_{p4} = (0.67 - 0.003 \, . \, Ø) \, .\text{UTS} \, . \, t \text{ for } 0 \le Ø \le 90 \qquad \text{equation 2}$$

$$(F_{p4} = (17.1 - 0.089 \, . \, Ø) \, .\text{UTS} \, . \, t \text{ in SI units})$$

If equation 2 is re-written in terms of the combined thickness of steel on either side of the connection it becomes:

$$F_{p4} = (0.335 - 0.0015 \, . \, Ø) \, .\text{UTS} \, . \, t \text{ for } 0 \le Ø \le 90 \qquad \text{equation 3}$$

$$(F_{p4} = (8.55 - 0.045 \, . \, Ø) \, .\text{UTS} \, . \, t \text{ in SI Units})$$

The coefficients of the equations now more closely resemble those of equation 1. Equation 3 implies that a stronger connection can be obtained if the total combined steel thickness in the connection consists of four layers rather than two. This has yet to be proven conclusively as the mechanical clinch used to develop equations 2 and 3 is a modified version of that used in the development of equation 1, to provide improved penetration and spread of the steel.

Equation 2 was used to predict the shear strengths of a separate series of tests, conducted by Pei and Kinney (1998). The results are compared in table 1. The experimental figures are the average of between 5 and 7 tests for each of the variables considered. It can be seen that, although equation 2 uses statistically derived coefficients, based on a separate data set and tested in a different test laboratory, there is good correlation between the experimental and predicted failure load.

angle of applied shear	Ultimate tensile strength psi (N/mm2)	thickness inches (mm)	average experimental failure load lbs (N)	predicted failure load lbs (N)	experimental / predicted
0	65091 (448)	0.027 (0.685)	1196 (5319)	1177 (5293)	0.99
30	65091 (448)	0.027 (0.685)	999 (4443)	1019 (4422)	0.99
45	65091 (448)	0.027 (0.685)	1033 (4594)	940 (4226)	1.10
60	65743 (453)	0.0265 (0.673)	846 (3763)	853 (3811)	0.98
90	65091 (448)	0.027 (0.685)	736 (3273)	702 (3158)	1.05
45	68000 (468)	0.035 (0.889)	1406 (6253)	1273 (5500)	1.10
60	68000 (468)	0.035 (0.889)	1180 (5248)	1166 (5220)	1.01

Table 1
Comparison between experimental and predicted results using equation 2
to predict the results of Wei et al (1998)

Further work on the behaviour of multi-layer connections is currently in progress.

Dis-similar materials

In many applications the layers of steel to be connected may be of differing thicknesses. Using conventional mechanical connections the strength is generally determined by the thinner of the layers. In mechanical clinching the orientation of the layers relative to the punch and die of the forming tool has a significant influence on the strength of the connection, figure 10. Some test results are presented in table 2. The values presented are the average of at least two test results for each configuration. Table 2 is divided into three separate sections. For a combination of two dis-similar materials the greatest strengths are obtained when the thicker material is placed on the punch side, irrespective of the direction of applied shear. Failure of the mechanical clinch tends to initiate on the punch side layer and therefore the strength is influenced more by the punch side material than the die side material. Also shown in table 2 is the corresponding shear strength for press joins formed of two equal layers of the thinner material. With the exception of one result the strength of press joins formed with two layers of dis-similar materials is stronger than the corresponding press join formed with two uniform layers of the thinner steel.

	Thicker steel on punch side			Thinner material on punch side			Equal steel thickness	
Angle of applied shear	punch side ins (mm)	die side ins (mm)	peak load lbs (kN)	punch side ins (mm)	die side ins (mm)	peak load lbs (kN)	thickness ins (mm)	peak load lbs (kN)
0	0.078(2.0)	0.059(1.5)	1013(4.51)	0.059(1.5)	0.078(2.0)	872 (3.88)	0.059(1.5)	888(3.95)
90	0.078(2.0)	0.059(1.5)	638(3.04)	0.059(1.5)	0.078(2.0)	548(2.44)	0.059(1.5)	474(2.11)
0	0.059(1.5)	0.039(1.0)	717(3.19)	0.039(1.0)	0.059(1.5)	433(1.93)	0.039(1.0)	400(1.78)
90	0.059(1.5)	0.039(1.0)	398(1.64)	0.039(1.0)	0.059(1.5)	296(1.32)	0.039(1.0)	287(1.28)
0	0.078(2.0)	0.039(1.0)	813 (3.62)	0.039(1.0)	0.078(2.0)	422(1.88)	0.039(1.0)	400(1.78)
90	0.078(2.0)	0.039(1.0)	438 (1.95)	0.039(1.0)	0.078(2.0)	317 (1.41)	0.039(1.0)	287(1.28)

Table 2 Strength of mechanical clinching in multi-layer joints

Variability of the strength of press joins

An important aspect in safe structural design is the inherent variability of the process. In order to study the variability of mechanical clinching ten samples of two different steels were tested with the load applied at both zero and ninety degrees. The results are summarised in table 3.

	steel no.1 UTS 69470 psi (479 N/mm2) thickness 0.059ins (1.5 mm)		steel no.2 UTS 54288 psi (378 N/mm2) thickness 0.079 ins (2.0 mm)	
	0 degrees peak load lbs (kN)	90 degrees peak load lbs (kN)	0 degrees peak load lbs (kN)	90 degrees peak load lbs (kN)
	926 (4.12)	550 (2.45)	1013 (4.51)	683 (3.04)
	1014(4.51)	584 (2.60)	1036 (4.61)	656 (2.94)
	982 (4.37)	595 (2.65)	1005 (4.47)	645 (2.87)
	959 (4.27)	584 (2.60)	1014 (4.51)	645 (2.87)
	1056 (4.70)	550 (2.45)	1014 (4.51)	661 (2.94)
	959 (4.27)	541 (2.41)	991 (4.41)	650 (2.89)
	977 (4.35)	541 (2.41)	1013 (4.51)	638 (2.84)
	1016 (4.52)	573 (2.55)	1036 (4.61)	683 (3.04)
	926 (4.12)	528 (2.35)	1016 (4.52)	649 (2.89)
	959 (4.27)	515 (2.31)	1036 (4.61)	706 (3.14)
Mean	964 (4.29)	557 (2.48)	1018 (4.53)	663 (2.95)
Standard deviation	30.3 (0.1347)	24.7 (0.1102)	13.8 (0.0613)	20.2 (0.0901)
variance %	3.14	4.45	1.35	3.06
characteristic strength kN	915 (4.074)	517 (2.30)	996 (4.43)	629 (2.80)

Table 3 Variability of press join strength.

The results indicate consistent behaviour. The standard deviation was calculated in accordance with British Standards (BSI 1987). The standard deviation is low, a maximum of 4.45% variance. During the forming process the steel layers are clamped in position and then subjected to an applied force and controlled deformation. The maximum deformation is limited by the shape and depth of the die. Thus if sufficient pressure is applied a consistent and repeatable join will be formed. Also presented in table 3 is the characteristic design strength of the press join calculated in accordance with British Standards and is within 7 % of the mean strength of the connection.

Summary and conclusions

The research to date on the strength of press joins indicates the following:

- The strength of mechanical clinching is primarily influenced by the thickness and Ultimate tensile strength of the steel being connected and the angle of applied shear.
- In connections consisting of four layers of steel comparable structural behaviour to two layer connections was observed.
- It has been shown that the strength of press joins in shear can be accurately predicted using expressions that assume a linear relationship between ultimate tensile strength, thickness and angle of applied shear.

- Consistent structural behaviour has been observed across the work of a number of researchers and the expressions developed to predict the strength of press joins have been shown to accurately predict the results of tests reported by other researchers.
- In connections using dis-similar thicknesses of steel, the steel layer on the punch side of the connection is more critical. The connection is strongest with the thicker layer positioned on the punch side. The strength of connections using dis-similar materials is generally stronger than the corresponding connection using two equal layers of the thinner steel.
- Mechanical clinching demonstrates consistent behaviour. The maximum coefficient of variance over a range of different samples was 4.45%.

Research into the strength of mechanical clinching in cold-formed structures forms part of an ongoing research programme into the structural behaviour of cold-formed steel structures at the University of Edinburgh. The broad aim of the current research is to develop a consistent and reliable method for the structural design of mechanical clinching. The scope of the investigation includes:

- Further study of multi-layer joints including three and four layers of steel
- Further testing of dis-similar materials to include a wider range of materials and thicknesses
- A comparative study of alternative forms of mechanical clinching
- An experimental study of mechanical clinching subjected to cyclic loading

As part of the programme a series of full scale test structures will be constructed to verify and develop the design methodology.

Acknowledgements

The authors gratefully acknowledge the support of the Engineering and Physical Science Research Council, Metsec PLC, British Steel PLC, Trichord Systems Inc. Eckold GMBH.

Appendix - References

Bober, J., (1987), ' Beitrag zum Fügen von stahlblecteilen durch örtliches einschneiden und Umformen' (Contribution to the joining of steel sheets through local cutting and re-forming), Dissertation, Technical University of Hamburg, Germany.

British Standards Institution, (1987), 'The Structural Use of Steel, Part 5, The design of cold-formed steel'. London, England.

Davies, R.J. (1996), 'The behaviour of press joining in cold-formed steel structures', PhD thesis, University of Edinburgh, Scotland.

Davies, R.J. Pedreschi, R and Sinha, B.P., (1996), 'The shear behaviour of press-joining in cold-formed steel structures', *Thin Walled Structures*, 23(3), 153-170.

Dedolp C.T. and Jaselskis E.J.(1997), 'Innovative wall system for construction industry', *Journal of Architectural Engineering*, ASCE, Vol. 3, No. 4, 178 - 184.

Liebig, H.P., (1987),'Press joining in sheet metal', *The British Engineer,* 27. pp 27 - 33.

National Association of Home Builders, (1996),'Prescriptive Method for Residential Cold-formed Steel Framing, U.S. Department of Housing and Urban Devlopment.

Pedreschi R., Sinha, B.P. and Davies, R.J. (1996), 'Advanced connection techniques for cold-formed steel structures', *Journal of the Structural Division*, ASCE, 123(2), 138-144.

Pedreschi R. and Sinha B.P. (1997), 'The shear strength of mechanical clinching in Trichord', Research Report, The Department of Architecture, University of Edinburgh.

Pedreschi R., Sinha B.P. and Lennon R., (1998), 'The shear strength of mechancial clinching in cold-formed steel structures', in press.

Pei, w and Kinney, C (1998), Shear strength of press joint connections of light gauge steel, Sustainable Steel, 1st International Conference on Steel in Green Building Construction, Orlando, Florida, March 1998.

Appendix - Notation

F_{p2}	the shear strength of press joins formed using two layers of steel
F_{p4}	the shear strength of press joins formed using four layers of steel
t	thickness of steel
Ø	angle of applied shear
UTS	ultimate tensile strength of steel

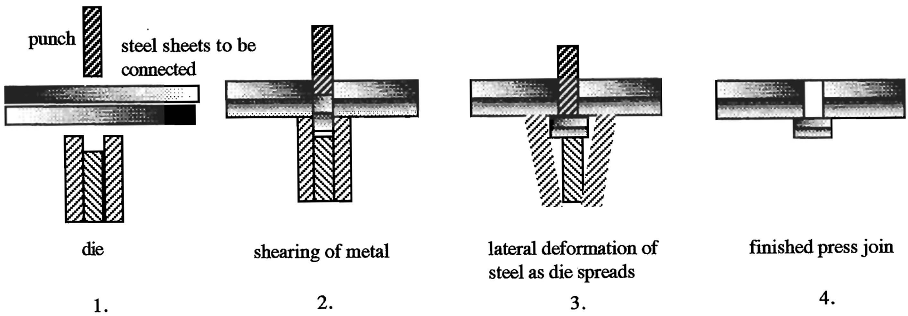

Fig.1 Process of forming a press join

Figure 2
The use of mechanical clinching in cold-formed steel trusses.

Figure 3
The use of mechanical clinching in steel studs

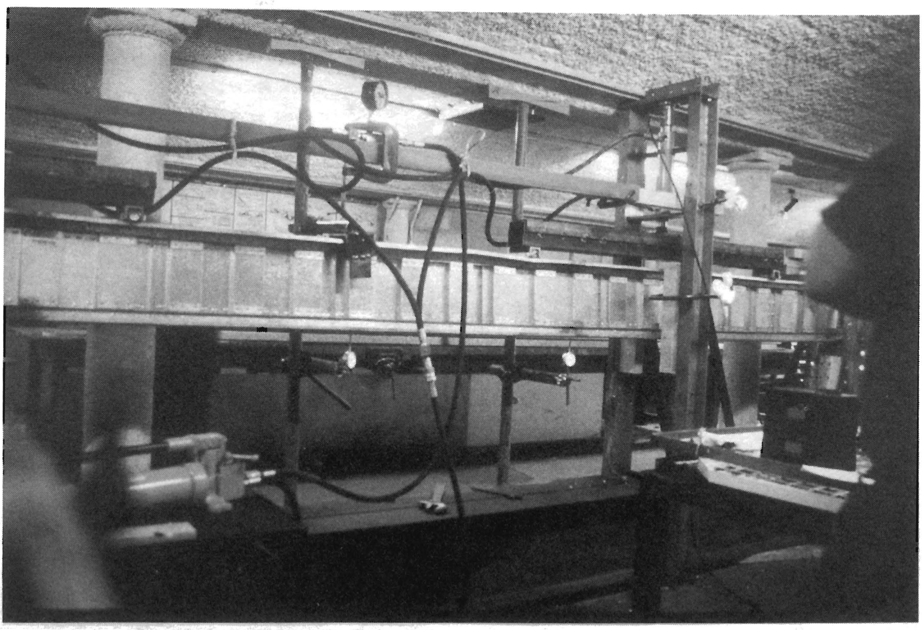

Figure 4
The use of mechanical clinching in fabricated steel beams

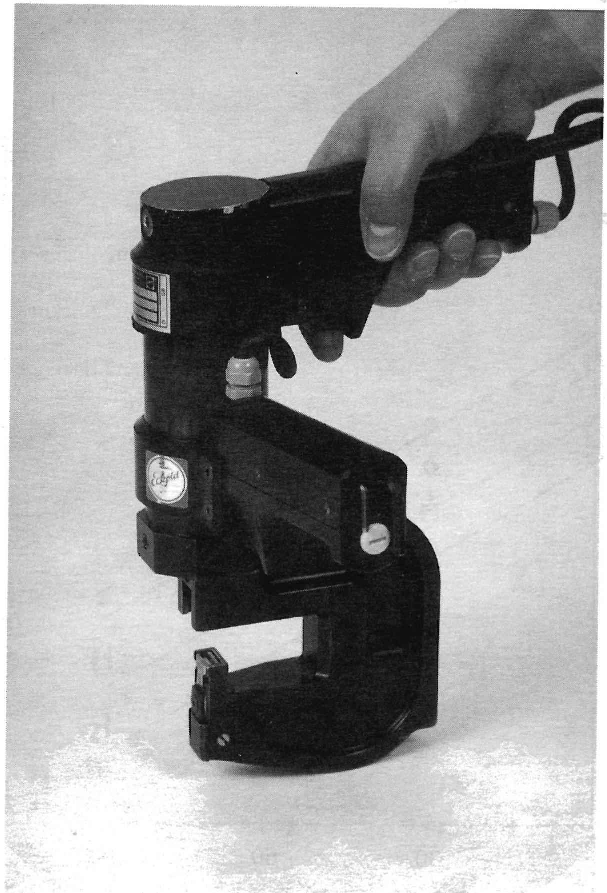

Figure 5
In the field tool for steel stud framing

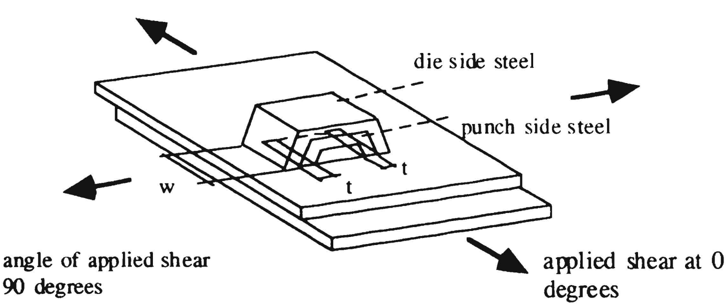

Figure 6
Typical press join showing orientation of applied shear

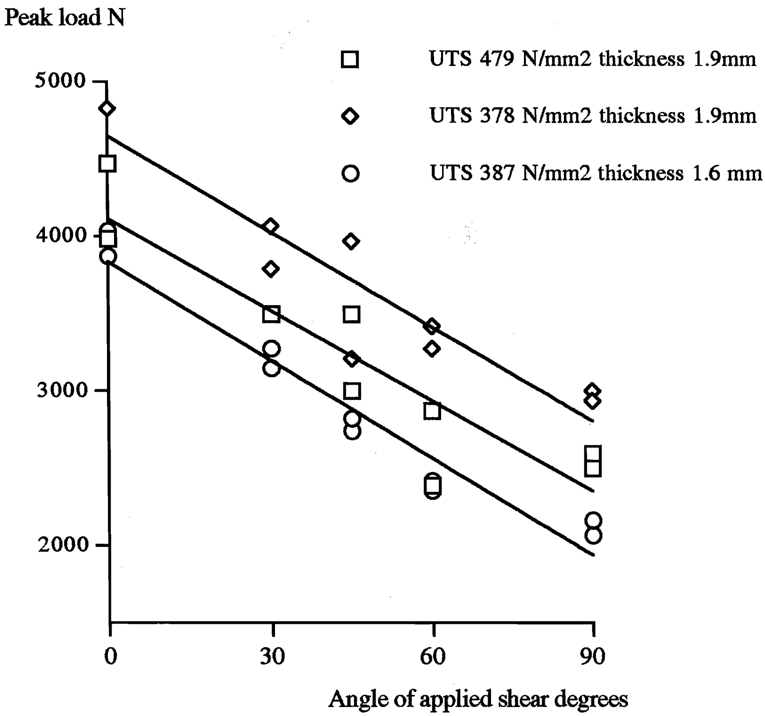

Figure 7
Typical relationship between angle of applied shear and strength

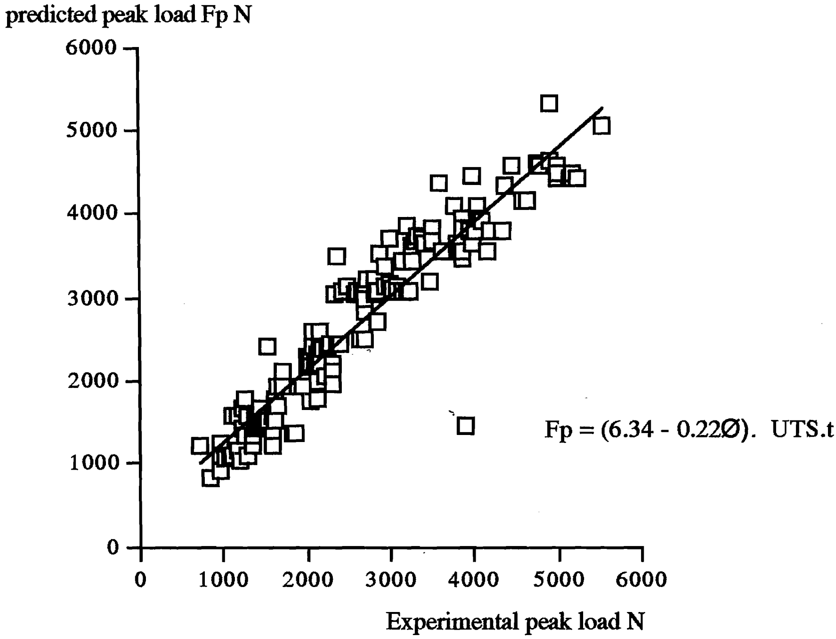

Figure 8
Comparison between experimental and predicted results using equation 1

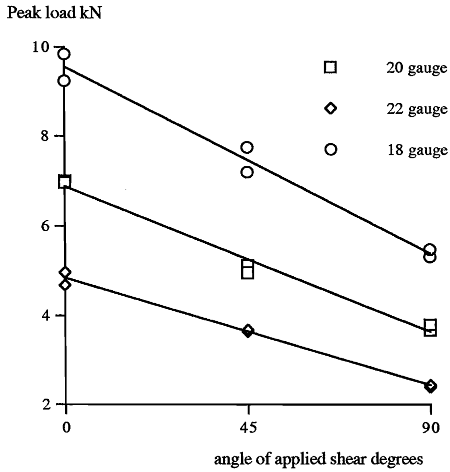

Figure 9
Typical relationship between angle of applied shear and falure load for multi-layered mechanical clinching

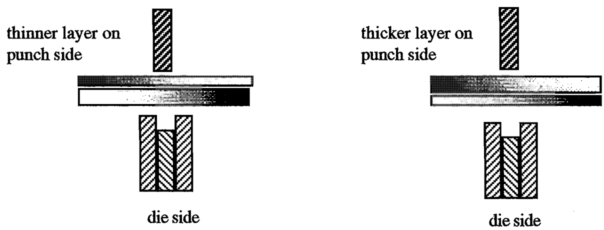

Figure 10
Dis-similar steel thicknesses - arrangement of steel layers