Design of Machines and Structures, Vol. 7, No. 1 (2017), pp. 23–31.

USE OF SURFACE RESPONSE METHODOLOGY (RSM) IN CLINCHING PROCESS

SZABOLCS JÓNÁS–MIKLÓS TISZA
Knorr-Bremse Rail Systems Hungary, University of Miskolc
1238, Budapest, Helsinki str. 105, 3515, Miskolc-Egyetemváros
szabolcs.jonas@knorr-bremse.com

Abstract: This study deals with the RSM by clinch joints especially the clinching of high strength steel type DP600. The goal is to find a relationship between the thickness of the clinched joints and the undercut or interlock (C-value). The joining procedure was made by a round TOX tool. The DP600 steels are dual phase (ferritic-martensitic) types (AHSS – advanced high strength steels). For the C-values non-linear finite element simulations were performed in the ANSYS system.

Keywords: *clinch joint, RSM, FEA*

1. INTRODUCTION

The response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for different types of processes (improving, optimizing, and developing). The RSM also has important applications in the design of new products. The most extensive applications of RSM are in the industrial world where several parameters potentially affect the results. The characteristic of the results is called the response. It is typically measured on a continuous scale. Most real world applications of RSM will involve more than one response. The parameters (or input variables) are sometimes called independent variables. The graphical representation of the fitted surface to the results has led to the term response surface methodology.

These joints are used mostly in automotive, computer and aircraft industries, but for instance according to the standards not allowed to use in food industry. This article is the first results of this research programme. The goal of the research is to determine the optimal parameters of clinched joints of high strength steels and aluminium. Furthermore to find a solution for fatigue evaluation and to replace some welded joints to clinched joints because of the cost of clinched joints are lower. The most difficult goal is to use the lowest number of tests and use the articles and other available material and test data to determine the relevant parameters. The clinch joints are quite new types of joints, the first patent was accepted in 1989. This joint can be done between 2–3 thin sheet plates. The material of the plates can be ferrous or non-ferrous, so this joint can realize dissimilar joints without any added material (weld material or glue). The joint made by metal plastic forming by a special tool.

After the patent the increasing industrial needs of this type of joints led the researchers to analyse the joint much more deeply. Several studies carried out the geometry optimization of the clinching tool to get better joints by different optimization methods. Other studies were carried out on the so-called hybrid joints. These joints have an adhesive layer between the sheets. These joints have higher strength but need much more time because the adhesive layer's drying is a time-consuming process [1], [2].

In this study the interlock was analysed. The analyses carry out on the field of the standard sheet plate sizes. FE simulations were performed in ANSYS to determine the different interlocks. From the result the size of the interlock will easily calculate and it is a basis for further analysis (e.g. prediction of pull out strength).

2. RMS MATHEMATICAL BACKGROUND

In general, a process involving a response y, that depends on the input parameters $\xi_1, \xi_2, \ldots \xi_n$. The relationship can be written as it follows:

$$y = f\,(\xi_1, \xi_2, \ldots \xi_n) + \varepsilon \qquad (1)$$

where the response function is f and the term of ε is represent other sources of variability not accounted for in f (e.g. measurement error, etc. assume that its mean is zero):

$$E(y) \equiv \eta = E[f(\xi_1, \xi_2, \ldots \xi_n)] + E[\varepsilon] = f(\xi_1, \xi_2, \ldots \xi_n). \qquad (2)$$

In much work it is a convenient to transform these variable to the so-called coded variables $x_1, x_2, \ldots x_n$. The coded variables are usually dimensionless with mean zero and standard deviation. It can be written as

$$\eta = f\,(x_1, x_2, \ldots x_n). \qquad (3)$$

The f is unknown there an approximation is needed. When the small zone of the independent variable space is appropriate a low-order polynomial (first or second order is used). For the case of two independent variables the first-order model in terms of the coded variables is

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2. \qquad (4)$$

If there is an interaction between the parameters, use the main effects model which can be written as

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2. \qquad (5)$$

Sometimes the second-order model is needed to define the response function. The following equation will describe that with interaction between the variables

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_1 x_1^2 + \beta_2 x_2^2 + \beta_{12} x_1 x_2. \qquad (6)$$

The second-order model has the ability for the easy estimation of the β values and flexible [9].

3. Clinching results

In this study DP600 type of advanced high strength steel was tested. The clinching tool was set up in an MTS servo-hydraulic testing machine. The maximum permitted load on the tool is 50kN. The set up can be seen in *Figure 1*. The specimens were pre-drilled for this application. Two holes were drilled which centralized the specimens on the one hand and prevented them moving on the other hand.

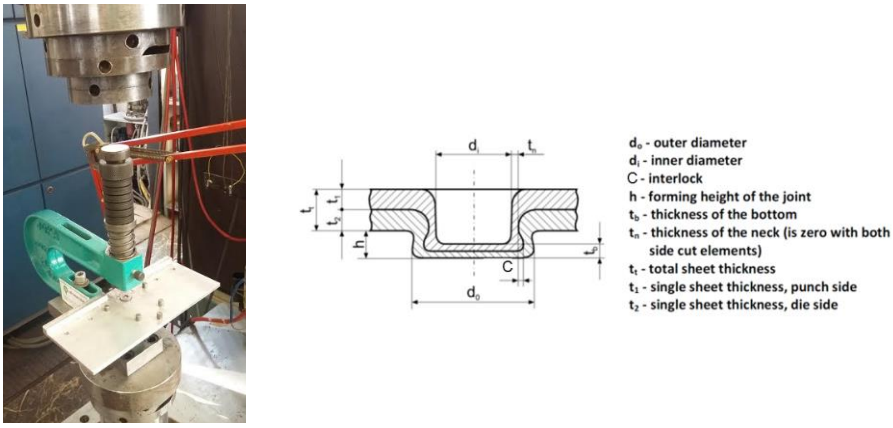

Figure 1. Clinching tool (TOX) and the relevant geometrical parameters of the joint [8]

After the measurement a microscopic investigation was done. The grinded section can be seen in *Figure 2*. The extended grains can be observed due to the forming procedure. The undercut can be also seen on the section. This curve between the formed sheets will be used to compare different simulated cases.

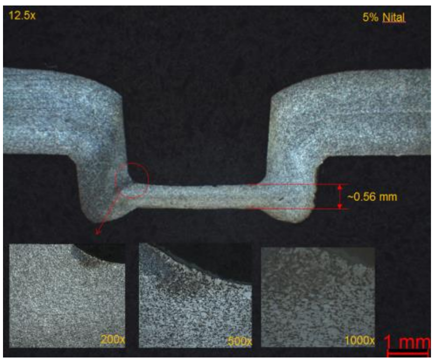

Figure 2. Microscopic investigation – cross section of the specimen after clinching

The FE simulation model was built in ANSYS WB 17.2 [3]. A 2D axisymmetric model presented below *(Figure 4)*. The tools were taking account as linear elastic materials. The sheets have multilinear isotropic hardening material model. The anisotropic behaviour of the sheets was neglected. The material model can be seen in *Figure 3*. The material law is fitted to the measured flow curve. The contact zones and the sheets also have a high mesh density. The boundary conditions applied to the model can be seen in Figure 4. The tools prescribed in all degrees of freedom on their sides and the punching tool is displacement controlled. It has got a –2.8 mm displacement in the vertical direction till the end of the simulation. Between the parts Augmented Lagrange contact behaviour was applied. The frictional coefficient between the sheets is 0.2 and for other contacts 0.01 values were taken into consideration. The contact stiffness behaviour was updated in each iteration.

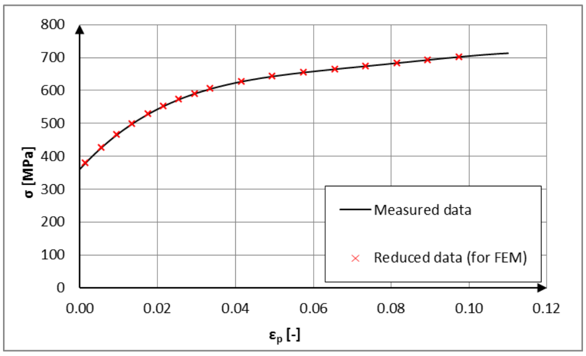

Figure 3. DP600 true stress-true plastic strain curve

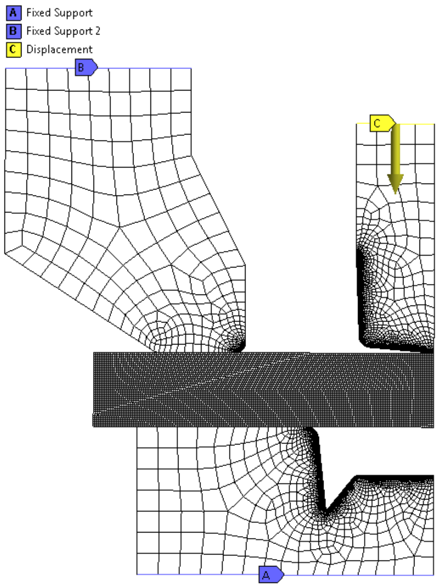

Figure 4. Boundary conditions of the model

4. RESULTS

The results of the simulations can be seen in *Figure 8*. The figure shows the equivalent plastic strain distribution of the sheets. The most affected zones are the neck region of the upper sheet where the punching tool is contacted with it and between the two sheets. *Figure 5* shows the measured and simulated sections of the sheets. The results show good agreement; we can say that the FE model is valid. With this model further simulations can be made to analyse the behaviour of the sheets with different thickness.

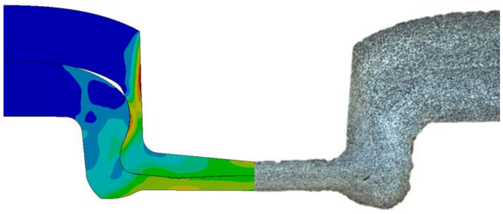

Figure 5. Comparison of the measured and simulated joints

4.1. Application of the RSM in clinching process

The variable filed was the standard deviation of the sheet thicknesses for cold rolled steel sheets (± 0.07 mm). The interlock was the unknown parameter. The "C" value is the difference (see *Figure 6*) of the maximum and the minimum value of the interlock.

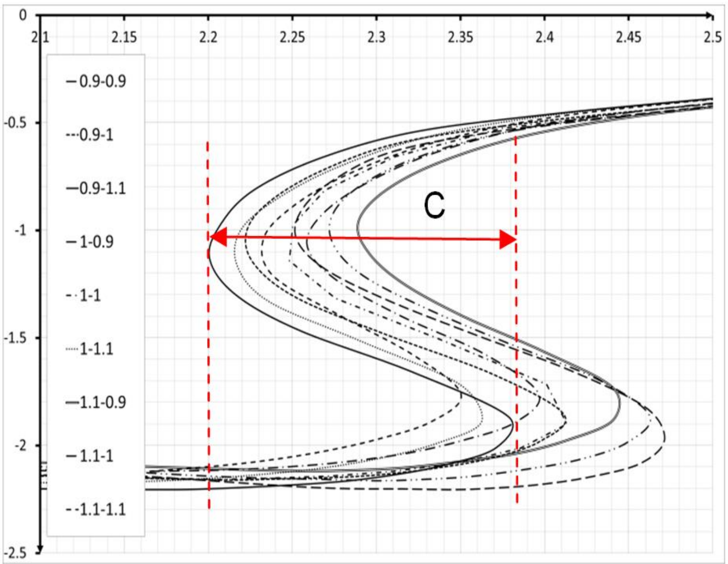

Figure 6. Simulated interlocks

From the simulation the following C values derived *(Table 1).*

Table 1. Variables

t_{upper} (X_1)	t_{lower} (X_2)	C
0.9	0.9	0.22
0.9	1	0.19
0.9	1.1	0.18
1	0.9	0.2
1	1	0.17
1	1.1	0.15
1.1	0.9	0.16
1.1	1	0.14
1.1	1.1	0.12

The f surface was fitted to the calculated values. The *Figure 7* shows the data points and the fitted surface. The vertical axle of it is the values of the C parameters; the other two axles are the thicknesses.

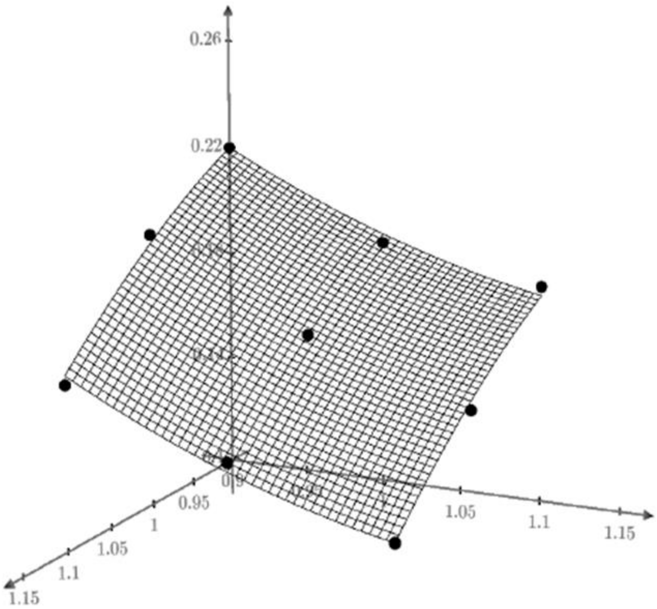

Figure 7. Fitted response surface with design points

A better view of the surface can be seen on the *Figure 8*. The colours show the effect of the parameters.

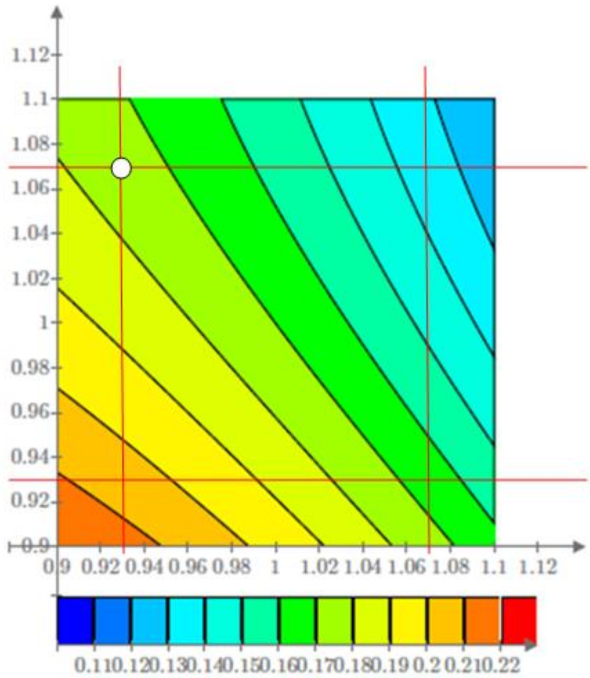

Figure 8. Contour plot of the response surface
(red squared area is the true size of the acceptable thicknesses)

The fitted surface's equation is a second order polynomial which can be written as

$$C_{prediction} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_4 x_1^2 + \beta_5 x_2^2, \qquad (7)$$

where the x_1 is the thickness of the lower sheet, x_2 is the thickness of the upper sheet. The mixed member (β_3 – see *Table 3*) can be neglected due its low value. The values of the parameters:

Table 2. Variables

β_0	β_1	β_2	β_3	β_4	β_5
0.67	0.717	–1.217	$-3.013 \cdot 10^{-15}$	–0.5	0.5

In absolute value the β_2 is almost the double of the β_1. From the *Eq. (7)* the predicted C value for $X_1 = 0.93$ mm and $X_2 = 1.07$ mm is $C_{prediction} = 0.175$ mm (white point in *Figure 8*). The simulated value for C is $C_{Ansys} = 0.178$mm. This can be seen in *Figure 9*. In opposite case the ($X_1 = 1.07$ mm and $X_2 = 0.93$ mm) the predicted value is $C_{prediction} = 0.165$ mm.

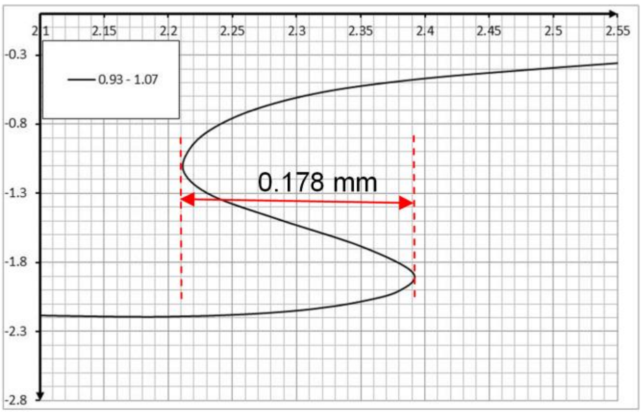

Figure 9. Undercut line of the re-checking dimensions

5. SUMMARY AND CONCLUSION

The FE calculations and the prediction model have been developed for thicknesses in case of DP600 type of steel. It can be observed that the thickness of the upper sheet has a greater effect on the C-value, which leads a higher undercut in the result and a higher pull out strength and finally a better joint.

The results show a very good agreement between the predicted and the calculated values. The deviance is ~2% which is acceptable. The RSM method is useful to determine unknown variables and to find relationships between distinct parameters. Further analyses are needed to find the relationships and the affecters for a better joint design.

6. REFERENCES

[1] T. SADOWSKI–T. BALAWENDER–P. GOLEWSKI: *Technological aspects of manufacturing and numerical modelling of clinch-adhesive joints*. Springer, 2015.

[2] L. KASCÁK–E. SPISÁK: Clinching as a non-standard method for joining materials of dissimilar properties. Zeszyty naukowe politechniki rzeszowskiej, Nr. 284, *Mechanika*, z. 84 2012.

[3] ANSYS WB 17.2 User's guide.

[4] P. Z. KOVÁCS–M. TISZA: Investigation and Finite element modelling of technological parameters of clinched joints. *Miskolci Egyetemi Közlemények*, Miskolc, X. kötet, 2015.

[5] M. TISZA–G. GÁL–A. KISS–Z. Z. P. KOVÁCS–ZS. LUKÁCS: Alakítható nagyszilárdságú anyagok klincs kötése. *Multidiszciplináris tudományok*, 4. kötet, 2014, 1. sz., 49–58.

[6] P. Z. KOVÁCS–M. TISZA: Klincs kötés technológiai paramétereinek vizsgálata, végeselemes modellezése. *Anyagmérnöki Tudományok*, 39/1, 2016, 7–18.

[7] Chan-Joo LEE, Jae Young KIM, Sang-Kon LEE, Dae-Cheol KO, Byung-Min KIM: Parametric study on mechanical clinching process for joining aluminum alloy and high-strength steel sheets. *Journal of Mechanical Science and Technology*, 24, 2010, 123–126.

[8] W. G. DROSSEL–M. ISRAEL–T. FALK: *Robustness evaluation and tool optimization on forming applications*. 9th Weimar Optimization and Stohastic Days, 2012.

[9] R. H. MYERS–D. C. MONTGOMERY–C. M. ANDERSON-COOK: *Response surface methodology – Process and Product Optimization Using Designed Experiments*. 3rd edition, 2009, Wiley.