IZBOR MINIMALNOG RADIJUSA TISKAČA KOD POSTUPKA "CLINCHING" SPAJANJA ZA OSTVARIVANJE MINIMALNE SILE JAČINE SPOJA

SELECTION OF THE MINIMUM RADIUS OF THE PUNCH IN THE 'CLINCHING' JOINING PROCESS FOR ACHIEVING MINIMUM JOINT STRENGTH FORCE

***Benjamin Čukle*[1]**

[1]*University of Zenica Faculty of Mechanical Engineering, Fakultetska 1, Zenica, B&H*

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REZIME

U današnjem vremenu, obezbjeđivanje kompetentnosti na tržištu direktno zavisi od promjena i poboljšanja internih proizvodnih procesa. Tako je, kao „bolja verzija" tačkastog zavarivanja, nastao proces „clinching". U našem rječniku još nema konkretnog prijevoda, pa se koristi opisno „postupak spajanja pritiskom". Kroz rad, predstavljen je postupak i rezultat eksperimentalnog istraživanja uticaja glavnih faktora u procesu.

Professional paper

SUMMARY

In today's market, ensuring competitiveness directly depends on changes and improvements in internal production processes. As a 'better version' of spot welding, the clinching process was developed. Since there is no specific translation in our terminology, the descriptive term 'joining by pressure' is used. This paper presents the process and the results of experimental research on the influence of key factors in the process

1. INTRODUCTION

The joining of sheet metals is commonly achieved through spot welding. Recently, the technique of 'clinching' has gained popularity as a joining method. Generally, this process, based on the principle of deformation, can be effectively categorized as a pressure-based joining technique. In the TOX®-Clinching process, the punch moves the material into the die. Through plastic deformation and reverse material flow, the joint is formed by creating an interlock that generates holding force [1]. The key question addressed was how frequently the tool, specifically the punch, needs to be replaced due to wear. Consequently, the problem was defined, requiring the design of an experiment to determine the minimum punch radius that meets the joint strength requirements. Using regression analysis and the Box-Behnken method, results were obtained and presented in this study. For the experiment, two different materials of varying thicknesses were selected, along with the required joint strength force.

2. PROCESS EXPLANATION

The pressure-based joining process enables the connection of sheet metals with varying qualities, surfaces, and thicknesses. This technique can accommodate a wide range of material combinations. Whether it involves steel, aluminum, copper, brass, or stainless steel, all these materials can also be joined in combinations. Continuous development and extensive application experience have resulted in tools with a long service life. The pressure-based joining process offers superior electrical conductivity compared to other mechanical joining methods. This makes it an ideal choice for electrical assemblies and devices. [2] These joints achieve high static forces, up to 70% of the strength of a welded spot. Figure 1 and Figure 2 represent steps and final joint connection.

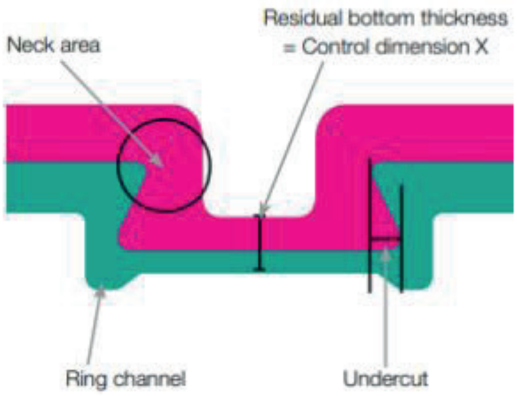


Figure 1. *Clinching process [1]*

They also benefit from strain hardening, maintain the surface coating, and are generally more cost-effective. Furthermore, the joining of different materials can be realized. Corrosion testing demonstrates that since the surface coating is not damaged during the clinching process, the corrosion-resistant properties of the joined sheets (e.g., galvanization) remain intact. The surface is not damaged by any deformation process – the coating moves with the material and remains undisturbed. Compared to spot welding, the clinching process does not exhibit the negative effects of notch sensitivity. This ensures that the joint strength remains consistent through various loading cycles. [3]

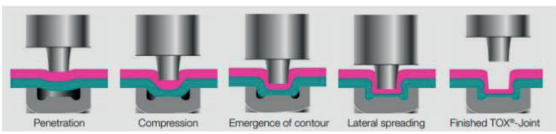


Figure 2 *Steps of the pressure-based joining process [1]*

In direct comparison with spot welding, the pressure-based joining process is approximately 40% more cost-effective in terms of investment, operational costs, and tool expenses. This is ensured by the following technical advantages [4]:

- Reduced investment due to the long tool service life,
- Low ongoing operational costs, as there is no need for additional material or component procurement,
- Rational production thanks to a high degree of automation,
- Energy savings, as heat generation is not required,
- No post-processing required and
- Continuous quality control ensures verifiable quality.

The tools used are called punches or press tools, which have several characteristics and dies. The required tool set consists of: a punch, a die, and a sheet holder. The mechanical joining of two or more sheets is based solely on the precise movement of the punch into the die; the sheets are locally deformed without the use of any additional components. The joint strength is the result of the S-shaped interlock. The quality of the process is strongly dependent on the precisely selected tools for production itself. [5]
Figure 3, presenting examples of some of the tools, is below.

Figure 3 *Tool types [1]*

3. MATERIAL SPECIFICATION, EQUIPEMENT AND PARAMETERS DEFINITION FOR EXPERIMENT

For experiment needs, two materials were used and presented in Tables 1 and 2:

- Metal sheet DX54D + Z – 1.0306 – Galvanized sheet metal for deep drawing (thickness 0.5[mm]) and
- DX54D + ZM – 1.0952 – (thickness 1[mm]).

Table 1. *Steel composition 1.0306 [6]*

C	Si	Mn	P		S	Cu	Ti	Al
max 0,12	max 0,5	max 0,6	max 0,1		max 0,045	-	max 0,3	-

Table 2. *Steel composition 1.0952 [7]*

C	Si	Mn		P	S	Cu	Ti	Al
max 0,08	max 0,5	max 0,5		max 0,025	max 0,02	max 0,2	max 0,3	min 0,010

During the process, three factors play a role:

- Punch radius,
- Penetration pressure and
- Penetration depth.

For the purposes of the experiment, a force of 1.5 [kN] was set as the defined requirement that the joint must withstand. After joining, the joined materials are taken to a tensile testing machine where the materials are separated, and the joint strength is measured. Testing machine is universal and can measure force up do 50 [kN]. Special tools are made for separating materials, and result values and diagrams are presented on computer

4. CONDUCTING THE EXPERIMENT

The goal of the experiment is to establish a mathematical relationship between the factors listed above and the output joint strength force. Referring to the Box-Behnken method for a 3-level factor experiment with 15 experimental points, punches with 3 different radii were manufactured. The required force is: $F > 1,5$ [kN]. Experiment was conducted in industrial environment with previously prepared tools with different radii. Tables 3, 4 and 5 define values of input and output parameters. The factors that can be varied and influence the holding force are:
R – punch radius [mm],
P – pressure [bar] and
h – depth [mm].
Regression analysis yields with final goal:

Table 3 Factors *P, R, h* levels

Levels	-1	0	1
R (*X*1)	0,1	0,4	0,7
P (*X*2)	45	50	55
h (*X*3)	0,8	1	1,2

$Rmin = f(F, P,h), \quad for\ F = 1,5$ [kN]

Table 4 Box-Bhenken matrix

Points	*R*	*P*	*h*
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	-1	0	-1
6	1	0	-1
7	-1	0	1
8	1	0	1
9	0	-1	-1
10	0	1	-1
11	0	-1	1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0

Table 5. *Joint force measurements*

Points	*R* [mm]	*P* [bar]	*h* [mm]	*F* [kN]
1	0,1	45	1	1
2	0,7	45	1	2
3	0,1	55	1	1,1
4	0,7	55	1	2,3
5	0,1	50	0,8	1,1
6	0,7	50	0,8	1,65
7	0,1	50	1,2	1,2
8	0,7	50	1,2	2,4
9	0,4	45	0,8	1,5
10	0,4	55	0,8	1,6
11	0,4	45	1,2	1,7
12	0,4	55	1,2	2
13	0,4	50	1	1,9
14	0,4	50	1	1,8
15	0,4	50	1	2

Data presented in Table 6 are obtained by using MS Excel's data analysis (regression).

Table 6 Summary output from MS Excel

Regression Statistics	
Multiple R	0,92529785
R Square	0,8561761
Adjusted R Square	0,81695141
Standard Error	0,18713348
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	2,293125	0,764375	21,82747431	6,17E-05
Residual	11	0,38520833	0,03501894		
Total	14	2,67833333			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-0,88125	0,74651692	-1,1804823	0,262705651
R	1,64583333	0,22053892	7,46277946	1,25702E-05
P	0,02	0,01323234	1,51144901	0,158857114
h	0,90625	0,33080838	2,73950132	0,019248598

Analysis comments:

- Determination coefficient $R = 0{,}925$ meets the required criteria and
- Two significant factors R and h according to P value table for $P > 0{,}05$.

Based on this analysis equation for force F can be concluded:

$$F = 1{,}64 \times R + 0{,}906 \times h \tag{1}$$

Now, R will be isolated:

$$R = \frac{F - 0{,}906 \times h}{1{,}64} \tag{2}$$

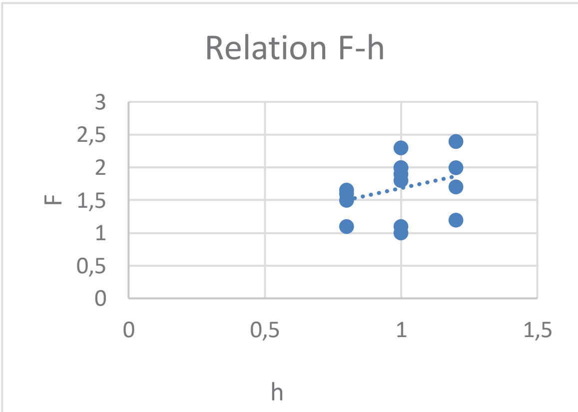
For known value of force F = 1,5 [kN] and standard depth in process h = 1 [mm]:

$$R = \frac{1{,}5 - 0{,}906 \times 1}{1{,}64} = 0{,}362[mm] \tag{3}$$

Result R = 0,362 [mm] represents minimal punch radius needed to meet the minimal force requirement F = 1,5 [kN]

Observation of significant factors on the response F:

Reading Figure 4 it can be concluded that larger punch radius R and larger depth value h have positive influence on force value F



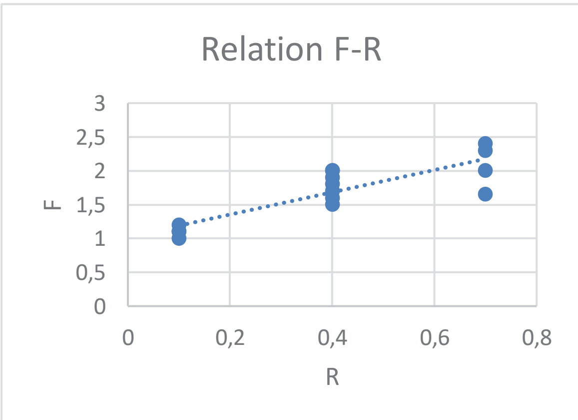


Figure 4. *Significant factors P and h influence response F*

5. CONCLUSION

Pressure-based joining, or 'clinching', is an intriguing material joining technique that can serve as an alternative to resistance spot welding. This method enables the joining of various materials, different material thicknesses, and even more than two materials simultaneously. Compared to spot welding, the process is cleaner and faster, with no generation of current or heat, and it offers better safety aspects. Additionally, the tools used in clinching are more durable than electrodes. The main drawback of this process is the higher initial investment cost for the machinery, which, however, proves cost-effective in the long term. The aim of this study was to demonstrate the clinching process through a specific example: determining the minimum punch radius required to achieve a predefined tensile force between two joined materials. Using the methodology of experimental design, an experimental matrix was established, and test samples were produced. These samples were then subjected to tensile testing to measure the separation force.

Subsequently, employing MS Excel and the Regression package, a relationship was established between the input factors *(R, P, h*) and the output *F*. Significant factors were identified, with the most influential being the punch radius *R*, as hypothesized. Since the punch radius wears out during operation, the task was to calculate the minimum radius the punch must have to meet the minimum tensile force requirement. By formulating an equation and inputting standard factor values from the process, the minimum punch radius required to achieve the specified force was calculated.

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Corresponding author:
Benjamin Čukle
Mašinski fakultet Univerziteta u Zenici
Email: benjamin.cukle.23@dl.unze.ba
Phone: + 387 62 361 121