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MECHANICAL CLINCHING PROCESS STRESS AND STRAIN IN THE CLINCHING OF EN-AW5754 (AlMg3), AND EN AW-5019 (AlMg5) METAL PLATES

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This paper presents the results of Finite Element Method numerical simulation performed onEN-AW5754(AlMg3), EN AW-5019 (AlMg5) plates subjected to mechanical clinching. The goal was to observe differences between aluminum plates in the same tool; and to determine the possibility of using the constructed tool for the clinching of Al-Al material combinations. This tool construction is to be produced and tested in laboratory conditions, to elaborate prospective results, and reach additional conclusions.

Key words: AlMg alloy, mechanical clinching, mathematical model, plates

INTRODUCTION

Mechanical clinching process is the metal forming process used for joining of metal sheets. Clinching tool is shown in the Figure 1.

The punch presses the upper sheet with the lower sheet into the matrix cavity, thus forcing the material to plastically deform with the intention of forming the interlock between two sheets in the formed joint (*f* in Figure 1).

The authors Y. Abe et al. have investigated joining of high strength steel and aluminum sheets with different tool configurations [1].

Xiaocong He1 et al. investigated strength and energy absorption of clinched joints with Finite Element Method, and experiments. Through FEM simulations they have found that the upper sheet is subjected to higher stress, and that the maximum stress occurs at the neck of upper sheet (possibility of cracking) [2].

Recent researches [3,4] provide information that tool geometry must be well tuned in order to produce quality joint between two sheets of metal. The tool/process parameters are matrix diameters (d_1, d_2), matrix height (h_1, h_2), matrix and punch angles (α_1, α_2), punch diameter d_3, different tool radii that influence material flow etc.

Eshtayeh M. and Hrairi M. investigated the possibility of joining dissimilar materials (EN AW-7075 with mild steel) by using Taguchi based Grey optimization on many numerical FEM simulations [5]. By using the multi response analysis they proved that the correct formation of sheet interlock was dependent on the punch diameter with face draft and side draft (angles α_2, α_3 from Figure 1), as well as on other tool parameters which are in accordance with results of authors [1-3] [4]. It has been recommended to include other joint parameters like sheet spring back, tensile separation force and damage effects in the further research to determine the influence on the joint bottom thickness and interlock [5].

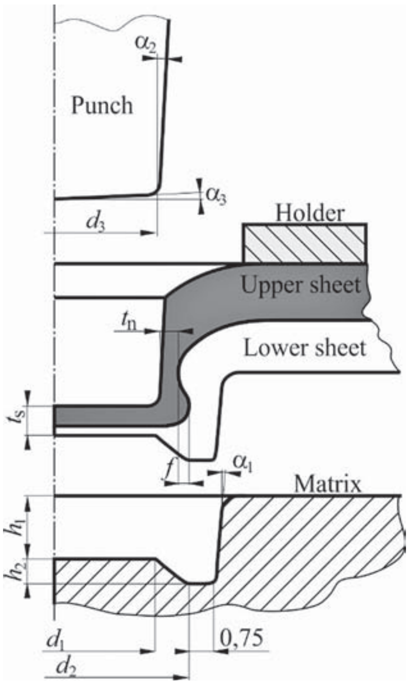

Figure 1 Tool geometry

C. Lee et al. investigated some of the process parameters (optimal tool geometry and dimensions) with the FEM method for the mechanical clinching of aluminum and high strength steel plates [6]. They varied punch/matrix clearance, type of groove shape and die depth in order to determine which of these had influence on joinability. They confirmed that the matrix radii had the most influence on join strength and the interlock value [6].

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This research was performed in order to observe possible interlocks with different materials, and to compare them with the previously obtained results. It was concluded that it was very difficult to find the best tool parameters without trials and errors, and that the FEM (Finite Element Method) method should be introduced to shorten time from material specifications to tool dimensions and construction.

MATERIALS

The material AlMg3 (EN AW-5754), and AlMg5 (EN AW-5019) were used in the FEM simulations. Both aluminum alloy materials are widely used in the general production.

From [7] the mathematical model for flow curve of AlMg3 was used in the form:

$$k_f = 270{,}1 \cdot \varphi^{0{,}11837} \cdot e^{\frac{-0{,}0038}{\varphi}} \tag{1}$$

The mathematical model for flow curve of AlMg5 was used in the form [7]:

$$k_f = 427{,}95 \cdot \varphi^{0{,}18207} \cdot e^{\frac{-0{,}00394}{\varphi}} \tag{2}$$

Both materials are usually delivered in warehouses in the annealed condition, thus the expressions (1, 2) from [7] are referring to the annealed condition.

The Young modulus E=70,4 GPa, and Poisson's factor ν = 0,33 [7] are also used.

For the input in program MSC.MARC it is necessary to exclude linear behavior of material, thus leaving only plastic material properties as an input. The conversion expression was used for the material input [8]:

$$\varphi_{pl} = \varphi - \frac{k_f}{E} \tag{3}$$

where k_f is the material flow strength and φnatural (logarithmic) strain.

DESIGN OF EXPERIMENTS

For the DOE (Design of Experiments) the central composite plan was applied. The Figure 1 shows tool geometries, which were simulated with both materials. The results are presented without ANOVA and mathematical models in order to show the most interesting points of producing optimal clinched joint, and as well as to emphasize the tool forces and stresses for those selected points. This paper is complementary to the authors previous research, in which it was explored how the tool constructed and optimized for the clinching of HC260Y steel plates behaved in the FEM environment with aluminum alloy plate at the same tool configurations.

Selected tool parameters are shown in the Figure 1.The first is the matrix diameter d_1, the second the ratio of matrix height (h_1 / h_2), and the third is the matrix angle α_1(combinations are shown in the Figure 2). The matrix dimension d_2 was always set as d_2 = d_1 + 1,5 mm, thus enabling the change of the punch/matrix clearance with the change of dimension d_2.

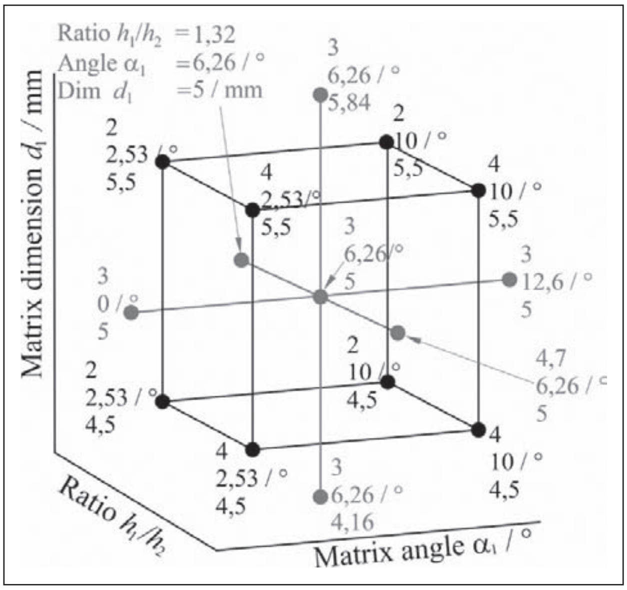

Figure 2 Clinching tool parameters from central composite design of experiments

Different heights of matrix were used, in order to take into account as much variable data as possible, the ratio of matrix heights h_1 / h_2 was used.

FINITE ELEMENT METHOD (FEM)

The mechanical clinching process with respectful tool parameters was simulated in the FEM program MSC.MARC. The matrix, punch, sheet, and sheet holder were modeled as axisymmetric geometries as shown in Figure 3. Both metal sheets were 1 mm thick. For the simulation purposes, the outer diameter was 20 mm in order to ensure that the ends of the sheet in FEM model were long enough from the clinched joint itself.

This was done to create computationally undemanding model, while maintaining sheet joint properties in the model.

The punch diameter was set as d_3 = 6,5 mm, with angle α_2 = 6°, angle α_3 = 5°, punch edge radii of 0,4 mm and this geometry was constant in all simulation cases.

In the FEM setup, model was axisymmetrical with the use of assumed strain and constant dilatation functions, which are to be used in the large strain deformation cases along with the lower order quadrilateral elements, in order to avoid possible problems with element locking due to overconstraints for nearly incompressible behavior [8]. The sheets were meshed with the lower order quadrilateral elements type 10 [8], with the size of 0,08 · 0,08 mm. Subsequent fine remeshing with the element edge length goal size of 0,05 mm was used with advanced grid regeneration algorithms. The "Advancing front quad" internal mesher, was activated when logarithmic strain was larger than φ = 0,15 and when the quadrilateral element was distorted (internal angle larger than 120 °) was activated.

The numerical simulation was set as large strain plasticity with large strain updated Lagrange option,

Table 1 **Results of FEM experiments**

No:	d_1 / mm	ratio h_1 / h_2	α_1 / °	AlMg3 (EN AW-5754)			AlMg5 (EN AW-5019)		
				f / mm	t_n / mm	t_s / mm	f / mm	t_n / mm	t_s / mm
1.	5	1,32	6,26	0,07	0,289	0,5	0,062	0,3	0,5
2.	5	3	12,6	0,018	0,32	0,6	0,004	0,332	0,6
3.	5,5	2	10	0,054	0,432	0,5	0,04	0,467	0,5
4.	4,5	4	2,53	0,0184	0,167	1,04	0,0036	0,177	1,04
5.	4,5	2	10	0,0865	0,137	0,6	0,0719	0,148	0,6
6.	5	3	0	0,077	0,204	0,8	0,065	0,22	0,8
7.	5	3	6,26	0,056	0,254	0,7	0,041	0,264	0,7
8.	5,84	3	6,26	0,097	0,44	0,4	0,083	0,459	0,4
9.	5	4,68	6,26	0,0345	0,24	0,84	0,023	0,253	0,84
10.	5,5	4	10	0,043	0,398	0,53	0,029	0,413	0,53
11.	4,5	2	2,53	0,078	0,149	0,79	0,0576	0,157	0,79
12.	5,5	4	2,53	0,083	0,334	0,6	0,067	0,353	0,6
13.	5,5	2	2,53	0,08	0,363	0,42	0,081	0,343	0,42
14.	4,5	4	10	0,016	0,186	0,91	0,009	0,19	0,91
15.	4,16	3	6,26	0,017	0,156	1,06	0,0033	0,15	1,06

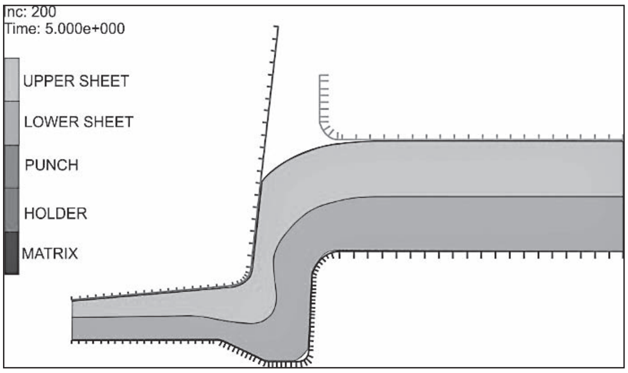

Figure 3 FEM simulation, bottoming of the clinched joint.

where additive decomposition method was used for matrix solving.

Contact control was done internally through the software with CTABLE option, where it was necessary to define possible deformable contact bodies (two sheets), and rigid bodies with prescribed motion (matrix was set as stationary, and punch had linear z-axis motion).

Friction factor of μ = 0,2 between punch /upper sheet, μ = 0,3 between aluminum sheets, μ = 0,12 between lower sheet/matrix with respect to research of [2,3]. Coulomb friction model with arctangent approach was used.

RESULTS

The results of numerical FEM simulations are shown in the Table 1. The largest interlock f (from the Figure 1) is desired to obtain the joint of good quality. Clinched joint is also characterized with the neck thickness t_n of the upper sheet (which is further correlated to the strains and stresses at which material breaks), and sheet bottoming thickness t_s as visible in the Figure 1. In the Table 1, there are three factors presented as follows: matrix diameter d_1 / mm ; ratio of matrix depth h_1 / h_2, and the matrix wall angle α_1 / °.

As referring to the Table 1, the optimal tool parameters are shown in the rows No. 8, No. 12 and No. 13.

Although it can be seen, that larger interlock f can be obtained also in other cases, they are not selected for the reason of excessive material thinning of the upper sheet. There are compressive loads it that area, so the stresses are not quite related to stress/strain curves obtained by tensile tests where necking of the specimen is dominant. For the selected cases the lower thickness of the joint t_s is in the lower data range, meaning that the tool will have to withstand higher stress during operation. Since the punch is of small diameter, it is very important to select appropriate tool material for the job.

The punch is the same in all the simulation cases, and if some other tool (matrix) sets will be made for the experiment tests, the punch will be compatible since it will have to withstand lower stresses.

In the Table 2, the true stress on the punch tool is shown with respect to the selected cases from the Table 1. Additionally, the punch was represented with quadrilateral 4-node axisymmetric elements as with modelled sheet elements. The only difference is that the punch was set to be in elastic mode due to the high yielding stress of the tool steel.

The Figure 4 shows equivalent von Mises stress at the node 3815 in the upper clinching tool (the case No. 8). This is the largest obtained tool stress which is relevant to the tool material optimal choice and tool life.

As of the previous research (which is at this time waiting publication), on the same tool configuration and the steel HC260Y plates, the tool steel was chosen

Table 2 **Upper tool (punch) stress for different cases**

	No. 8: σ / MPa	No. 12: σ / MPa	No. 13: σ / MPa
AlMg3	1 233 (node: 3 825)	1 159 (node 13 526)	1 270 (node 3 826)
AlMg5	1 512 (node 3 815)	1951 (node 13 519)	1 461 (node 3 825)

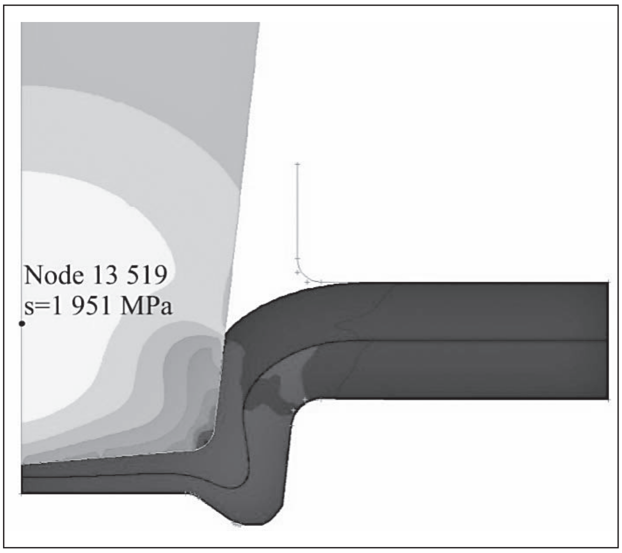

Figure 4 Equivalent von Mises stress (maximal) for the No.8 case (AlMg5) from the Table 2

as the punch steel EN 1.2379 / X153CrMoV12, since it had transverse rupture pressure of 3500 MPa [9,10].

Material (X153CrMoV12) is also known as D2 steel, which can be heat treated to 60 - 63 HRC. This hardness is desirable for the clinching tool since it has excellent wear resistance, and small tool deformation. Both punch/matrix sets for the experiments are to be made of solid X153CrMoV12 steel bar, machined and heat treated by quenching from 1 000 -1 050 °C, and subsequently tempered at 150 - 200 °C [9] in order to achieve optimal hardness.

CONCLUSION

This research paper focuses on variations of the dimensions, the matrix inner cavity dimension, the ratio of matrix depths, and the matrix wall angle, aiming to assess the influence of parameters on the amount of sheet interlock in mechanically clinched joint. Two aluminum alloy materials with similar mechanical properties, AlMg3 and AlMg5 sheets were investigated. The goal of this research was to find out tool stresses during the clinching process of aluminum sheets. It was shown that the clinching tool designed for the clinching of steel plates could withstand stress of maximum σ = 1 951 MPa without problems. Different friction conditions were used, and are specific to the aluminum alloys and related to the research of [2,3]. Since the tool stresses are bearable for the selected tool steel, future research will be performed on the abovementioned tool. The presented tool configurations will be made on computer numerically controlled (CNC) machine, in order to compare FEM results with the laboratory experiment results.

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Note: The responsible translator for the English language is Martina Šuto, prof., UNIOS, Osijek, Croatia.