Finite Element Modeling of Clinching Process for Joining Dissimilar Materials

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Abstract. Clinching is one of the important new joining techniques, in which two plate metal parts are locally plastically deformed by mechanical interlock. Clinching is a mechanical joining method by using simple tools that consist of a punch, a die, and a blank-holder. The shapes of these tools are the most important parameters that control the final geometry of the clinch joints which in turn strongly affect the strength and quality of the final joint. In this study, finite element simulations are carried out to investigate some of the difficulties regarding the optimization of the process parameters, and major expected geometric parameters that will influence the strength, joinability, and the quality of the joint.

Introduction

Joining dissimilar materials, such as aluminum and steel is practiced in various industries from automotive, railway vehicles, and truck manufacturing to computer and furniture fabrication. Traditionally, resistance spot welding is the prevailing connection technology for several industries' constructions. Due to technical issues, problems, cost, time, pollution, and other reasons, industries have begun to shift from traditional joining methods to mechanical joining methods such as clinching (often called mechanical interlock connection process). The clinching joining method has become a popular alternative to conventional resistance spot welding due to the rising use of several materials, which are hard or impossible to be joined by welding. Until the 1980s the technology was not widely used in industry [1]. Just in recent years has the interest in the use of clinching joining increased in industry, as clinching was successfully implemented to complement or even replace other joining techniques such as spot welding [2]. In the clinching process, two sheets of metal are joined using at most a die and a punch. The clinching joining consists of two principal actions, forming and drawing, that cause the creation of the interlock between the sheet's metal layers. During the process, the sheets are plastically deformed; the punch is moved with the required force depending on the thickness and the strength of the materials to be joined, whereas the die is fixed during the process. Furthermore, the size of the tools and friction coefficient are some of the major factors that influence the clinching joint [3].

Regrettably, this process is still early in its development despite rapid advances in recent years; it requires much more research to achieve the point where accuracy, high quality, and optimal strength of the joints become comparable to industry standard. In order to be adopted on a larger scale, some aspects of the process need to be further studied and clarified. It is impossible to achieve this goal without a complete understanding of the mechanics and relevant parameters. Therefore, this article explores the use of the finite element (FE) method to predict and optimize the main parameters that affect the clinching process.

Clinching Forming

Single-step clinching is the most commonly used clinching method in automotive joining operations. The process sequence is illustrated (Fig. 1) in four steps:

1. The punch and blank holder move downward, the work pieces are clamped and fixed by spring force of the blank holder.
2. By action of the punch, the material flows into, the bottom die cavity forming a cup. The process parameters and dimensions of the punch and die are finely tuned to the sheet thickness of the work pieces. This insures that no material is laterally drawn into the joint from surrounding area.
3. Finally, the thickness of the cup's bottom is reduced by upsetting, and the material forced into the die groove and in lateral direction, forming the necessary undercut.
4. After reaching a predetermined maximum force or a predetermined displacement, the punch is retracted and the clamping force relieved. The joint connection requires no finishing.

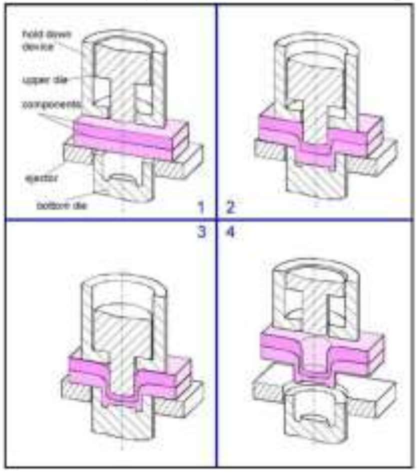

Fig. 1 Single-step clinching without cutting [4].

Clinching Process Simulation

Material Model. Regular tensile test is required to obtain the conventional stress-strain curve. In our basic model, the materials used are as follows: Steel 201 sheets & Aluminum 5052-H34 both with same thickness of 1.2 mm (punch and die side) – the mechanical properties are shown in Table 1.

Table 1: Mechanical properties for Steel 201 and Al 5052

Material:	Steel 201	Al 5052-H34
Mass Density ton/mm^3	$7.7503\ e^{-9}$	$2.689e^{-9}$
Young’s Modulus	$1.972\ e^{5}$ MPa	$7.0327e^{4}$
Poisson’s Ratio	0.29	0.33
Yield Stress	309.79 MPa	203.27

The true stress-strain curve for these materials can be approximated by using the power law: material was modeled to be isotropic.

$$\sigma = K\ (\varepsilon_0+\varepsilon^{pl})^n. \tag{1}$$

where: σ: true stress, K: deformation resistance, ε^{pl}: equivalent plastic stains, ε_0: initial deformation, n: hardening exponent

Finite Element Model. The Finite-element analysis was carried out using the commercial software LS-DYNA with the explicit finite-element formulation. The clinching process is considered as axisymmetric in this study. The piecewise linear plasticity material model was used in the study in simulating the basic model. The used data is available from different sources and publications, as shown in Table 1. The axisymmetric 2D shell element was used with four nodes rectangular element shape, with hour-glassing control to avoid the elements locking. In addition, the tools (punch and die) in the FE models are considered as totally rigid. Due to the shortage of information regarding measuring or calculating the friction value from literatures, Coulomb friction was used in the basic model with different values, such as, 0.15, 0.27, 0.25, between upper sheet and blank holder, upper sheet and lower sheet, and between lower sheet and die, respectively. After that, boundary conditions are; upper sheet to be fixed far away from deformation occurrence. Next, the lower sheet is completely free during the clinching simulation process. Moreover, adaptive remeshing technique was used due to the severe element distortion during the process operation because of the large plastic deformation. Furthermore, contact was modeled using the 2D automatic surface to surface. The clinching process was simulated by applying a specified downward displacement (8 mm/s), to every node within the punch; the max stroke of the punch is 3.7 mm. Fig. 2 shows the simulation of the process.


Time: 0.1 sec Time: 0.2 sec Time: 0.3 sec Time: 0.4 sec Time: 0.5 sec

Fig. 2 Finite element simulation of the clinching process (steel-steel thickness 1.2 mm)

The reduction in thickness of the flat bottom mentioned in previous studies was evaluated by measuring the clinched resistance (strength) experimentally, where the data was compared with the numerical one [5,6]. The results obtained from simulating the basic model shows that the thinning of the sheet on the bottom of the joint is approximately 75 percent from the original thickness of the two sheets. The clinching process parameters need to be optimized to get more thickness in the bottom of the joints without affecting the other parameters, and this is achieved not only by optimization but also by obtaining an accurate experimental data for the material behavior and properties in order to reach the maximum strength and the highest quality of the joint. Fig. 3 shows the thinning of the sheets in different locations as well as the Von Mises and the effective plastic strain contour plots of the final clinched joint.

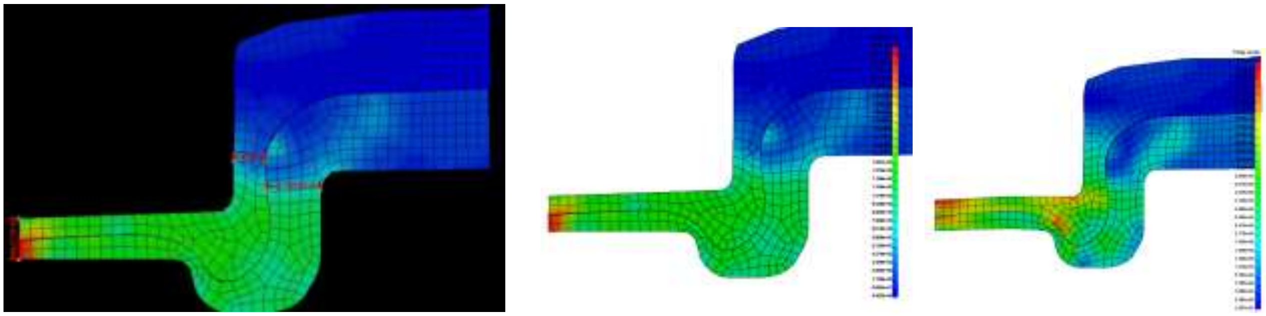

Fig. 3 Final clinched joint (a) bottom thickness (b) Von Misses stress (c) effective plastic strain

Furthermore, there are two important parameters that will affect the strength of the clinched joint: the thickness of the upper sheet neck and the interlock. The dimension of the interlock and the neck thickness of the upper sheet obtained from the simulation of the basic model are displayed in Figure 4. Moreover, the interlock value shown is very close to the value obtained from the literature.

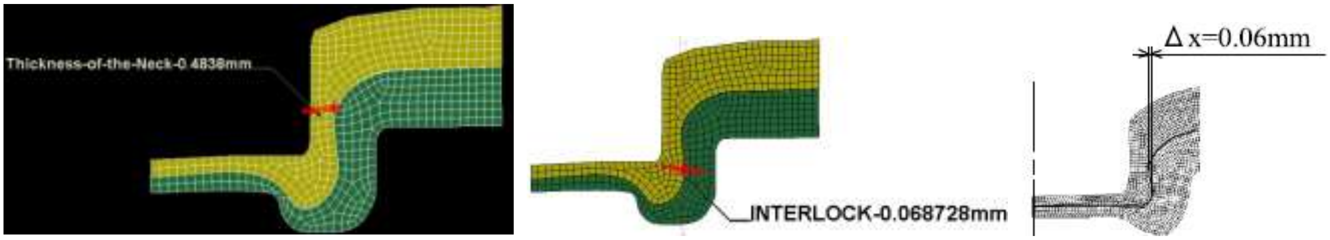

Fig. 4 Final clinched joint (a) neck thickness (b) interlock from simulation of the basic model (c) interlock from the literature [6]

Fig. 5 (a) illustrates the pressure-time curve of typical element in the simulation [6]. Fig. 5 (b) shows the pressure versus time curve of an element in the basic model simulation. There is some discrepancy between the two curves due to the mesh size difference and the material properties and behavior. However, the two graphs show approximately the same trend.

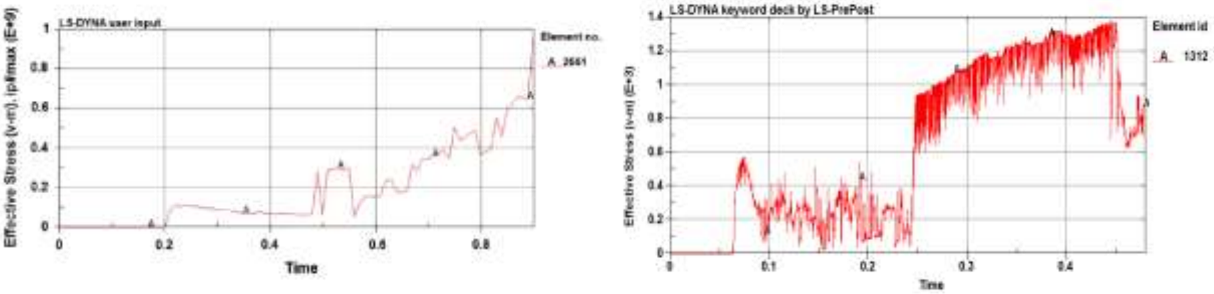

Fig. 5 Effective stress vs Time (a) Element A 2661 [6] (b) Element from the basic model simulation

Conclusion

The preliminary results of the present study of the clinch process show the ability to model the clinching forming process and to predict the strength of the clinched joint. The simulation of different clinching process configurations will help in determining the optimization of the tools and can lead to new sensitive parameters. The validation of the results will be achieved experimentally or by comparing the results with the results obtained from open literature reviews and studies.

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