Modeling strategy for clinched joints in assemblies

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Modeling strategy for clinched joints in assemblies

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Abstract. Clinching is a mechanical joining technique which involves severe local plastic deformation of two or more metal sheet parts resulting in a permanent mechanical interlock. Today, it is a reliable joining technique used in automotive, HVAC and general steel constructions whilst still gaining interest. As it is not computationally feasible to include detailed sub models of these type of joints in FE simulations of real-life clinched assemblies, this paper proposes a methodology to represent these connections with simplified elements. In order to calibrate the parameters governing the equivalent model, a simple shear lap and pull-out test is used. This methodology is applied to clinched configurations and validated using a modified Arcan test in which both shear and pull-out loads are considered.

1. Introduction

For both economical and environmental point of view, lightweight constructions have gained more interest in recent years. The need to join dissimilar, coated or hard to weld lightweight materials, led to rapid development of mechanical joining techniques such as clinched joints. Clinching is a mechanical joining technique that involves severe local plastic deformation of two or more sheet metal parts, resulting in a permanent mechanical interlock.

The forming process and the mechanical performance of a single clinched joint have been extensively investigated by finite element simulations [1, 8, 9]. The clinched region is a complex shaped zone where the material state varies from point to point. If a structure or assembly contains many such joints, it is unrealistic because of the computational costs and means to build a numerical model containing a huge number of detailed sub-models. The goal in this work is to obtain a methodology to replace the complex full-scale clinch model in numerical simulations for quasi-static loading. The focus is on the global force displacement response up to maximum force. Therefore a relatively simple connector element can be used. Simplified models are already successfully used in other joining techniques such as bolts, spot welds, self piercing rivets etc. Today, however, the possibilities in this field for clinched joints have not yet been thoroughly investigated.

2. Methodology

2.1. Experimental reference case

DC01 sheet metal was selected because it has excellent deep drawing properties, is widely available as sheet metal and is therefore ideal to use as clinching material. The material properties of DC01 sheet metal (thickness 1 mm) were obtained by means of an uni-axial tensile test. This material was joined with the Non Cutting Single Stroke (NCSS) clinch technology

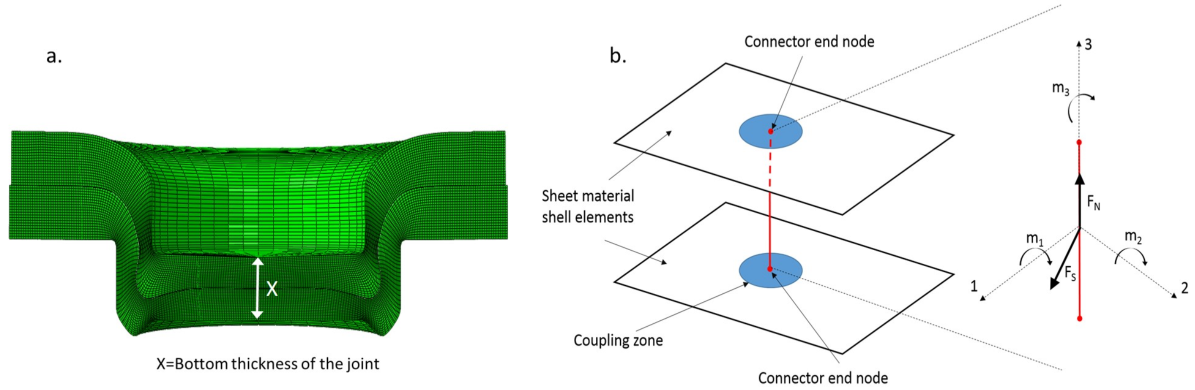

Figure 1. Principle of equivalent modeling: a. full scale model b. equivalent model

using an extensible die. The average clinch diameter was 8 mm with a bottom thickness of X=0.55 mm at the base of the joint. In order to calibrate the numerical models, a reference case is necessary. Therefore a simple pull-out and shear lap experiment are performed on a clinched specimen. These experiments will be used to calibrate the equivalent model.

2.2. Equivalent model representation

For modeling clinched joints a connector formulation is used. This formulation has been proven to be optimal in terms of computational cost compared to a virtual element formulation [6]. The connector formulation consists of a beam like connection with a local coordinate system and 6 degrees of relative motion (U1,U2,U3,UR1,UR2,UR3), all in which elastic and plastic behaviour can be introduced. The end nodes of this connector are coupled to a coupling zone onto the shell elements which acts as the clinched joint influence area on the sheet material (Fig. 1 b.). To couple the end nodes with the influence zone, Weyer S et al. [5] and Grujicic M et al. [4], suggested to use a structural distributed coupling. This coupling divides the moments and forces acting on the connector over the elements of the influence area which can cause local deformation of the coupling zone. As a result, the model will have a lower stiffness compared with the experimental results (Fig. 2 a.). It can be concluded that the influence zone of the clinched joint can be represented as a very stiff zone inside the sheet material which restricts the sheet deformation in this zone. The use of a kinematic coupling is therefore a good approximation for a clinched joint (Fig. 2 b.). The radius of the influence zone is assumed to be equal to the clinch joint maximum radius.

2.3. Connector elastic behaviour calibration

Uncoupled elastic behaviour will be used. This means the spring stiffness's D_{ii} are defined independently for each load direction. Following equation is used to calculate the elastic response of the connector:

$$F_i = D_{ii} \cdot u_i \tag{1}$$

To calibrate the connector spring stiffness's D_{11}, D_{22} and D_{33}, respectively the two shear and the normal directions of the connector, a rigid stiffness is initially assumed as connector section in both numerical models. Through comparison with the experimental force displacement curves of the shear lap and pull-out tests, the connector stiffness is calibrated. Due to the limited bending of the clinched joint, D_{44} and D_{55} (bending around the radial axes) are assumed to be

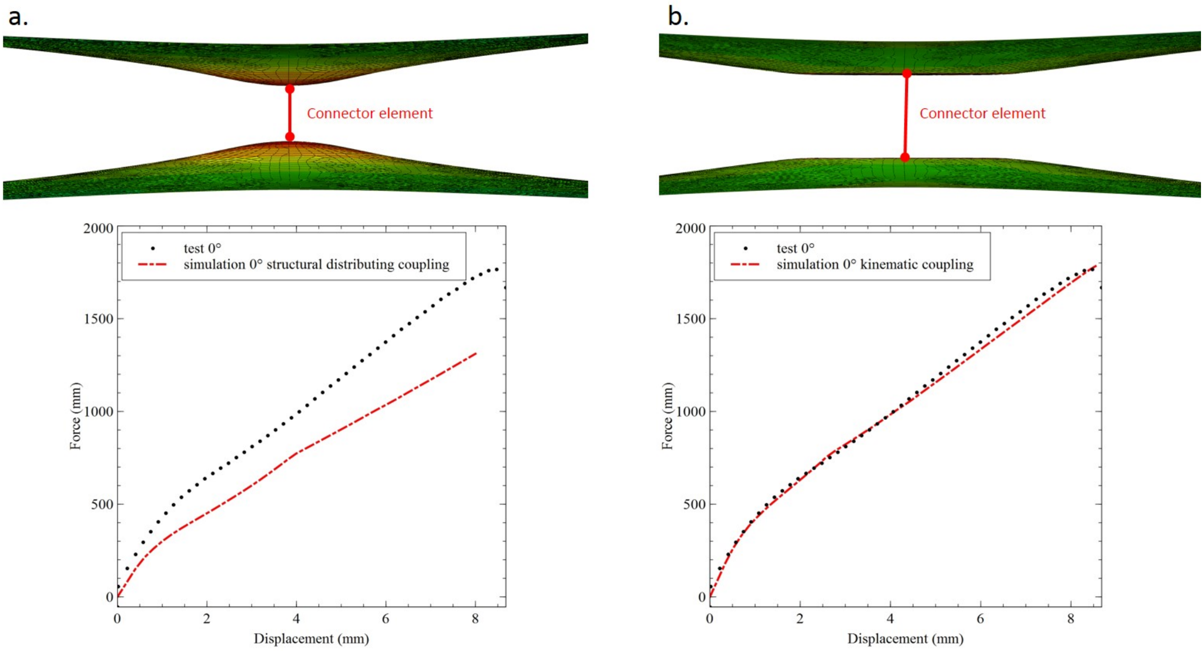

Figure 2. Coupling methods: a. structural distributing coupling b. kinematic coupling

rigid. The bending around the normal axis, D_{66}, is assumed to be free as the joint can rotate around the normal axis with limited amount of resistance.

2.4. Connector plastic behaviour calibration

To describe the plastic behaviour of the connector element, a independent force displacement based hardening law is defined for each of the main load directions (shear and normal) exerting on the connector. For mixed-mode load conditions, the connector acts as the resultant of both hardening laws. These hardening laws are calibrated using the experimental results of the reference pull-out and shear lap tests. The equivalent yielding force can directly be derived from matching the elastic connector simulation with the experimental reference results (equation 2 and 4). The plastic displacements however, retrieved from the experimental reference cases, need scaling factors $K_{u,N}$ and $K_{u,S}$ to determine the correct displacements at the connector end nodes (equation 3 and 5). The experimentally measured plastic displacement components require to be scaled to the plastic displacement at the connector end nodes. Indeed, it is physically impossible to obtain the latter values directly from the reference experiments, and, consequently, a scaling factor K needs to be introduced. The specimen geometry and type of test determine the size of the scaling factor. By matching the simulations with the reference case experiments, the scaling factors and hardening laws are determined. The resulting connector hardening laws are independent of the specimen geometry and size.

For the normal direction:

$$F_N = f_3 \tag{2}$$

$$u_N^{pl} = u_3^{pl} \cdot K_{u,N} \tag{3}$$

For the shear direction:

$$F_S = f_1 = f_2 \tag{4}$$

$$u_S^{pl} = u_1^{pl} \cdot K_{u,S} \tag{5}$$

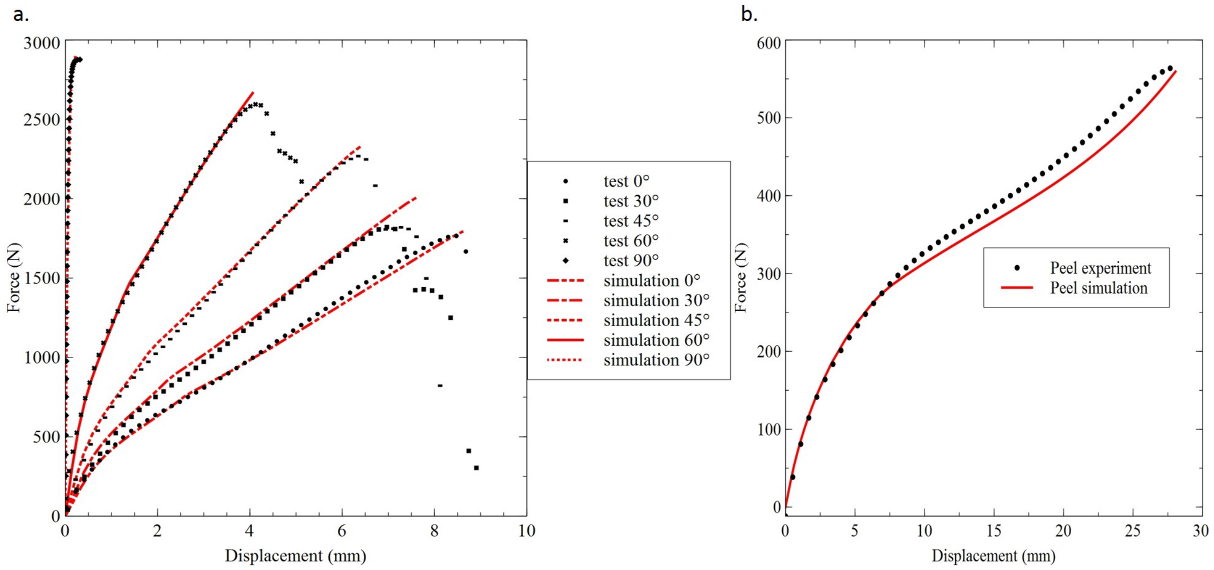

Figure 3. Results: a. DC01 Arcan test results b. DC01 Peel test results

3. Validation

In practice, the clinched joint will be exposed to a combination of shear and pull-out loads. In order to validate the calibrated joint behaviour, mixed-mode load conditions need to be applied on the joint. To achieve that, a modified Arcan test [7, 8] was performed for 3 different load cases (30°, 60°, 45°). Our in-house produced modified Arcan fixture was mounted in a single axis tensile machine. This test has been widely accepted as validation method for equivalent models [2, 3, 5]. Digital Image Correlation (DIC) [10] was used to track the displacements of the Arcan fixture. The simulation results of the Arcan test (Fig. 3 a.) show that the presented methodology for clinched joints gives a accurate prediction of the global force displacement behaviour of the clinched specimen up to maximum force. Additionally, the influence of bending moments was investigated using a peel test on a clinched specimen (Fig. 3 b.). Comparing the results of the simulation with the experiment, it can be concluded that the moments acting onto the joint have no substantial influence on the intrinsic deformation behaviour of the joint as the equivalent formulation does not include bending moments and is still able to reproduce the force displacement response.

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