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Procedia CIRP 12 (2013) 163 – 168

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8th CIRP Conference on Intelligent Computation in Manufacturing Engineering

Optimization of the clinching tools by means of integrated FE modeling and artificial intelligence techniques

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Abstract

In the present work, an optimization of the clinching tools involving extensible dies is performed to increase the clinched joints strength. The clinched joint strength is influenced by the lock parameters, which in turn depend on the clinching tool geometry. A finite element model is developed to predict the effect of the clinching tool geometry on lock parameters and recursively optimize the tool geometry. In order to reduce the number of FE simulation runs, an artificial Neural Network (ANN) model is utilized to predict the behavior of clinched joints produced with a given clinching tools configuration. The ANN is trained and validated by using the results of the finite element model produced under different clinching tools configurations. Finally, an optimization tool based on a Genetic Algorithm tool was developed to demonstrate the effectiveness of the proposed approach.

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Selection and peer review under responsibility of Professor Roberto Teti

Keywords: mechanichal fastening; joining; forming, clinching, metal sheet

1. Introduction

Clinching is a metalworking process by which two or more metal sheets are joined locally without the employment of additional elements such as screws, pegs, rivets, bolts and nuts, resulting in a reduction of the production cost and the run time [1]. In addition, mechanical clinching does not require a surface preparation such as competing technologies e.g. drilling (riveting), cleaning and roughening of the surface (adhesive boding) and other types of surface preparations (arc welding). This method is also suitable for those applications where a good corrosion resistance is required; because of such advantages and the flexibility of the process, clinching is utilized in a wide range of applications and can be applied to different materials such as low carbon steels, high strength steels [2], aluminium alloys [2], magnesium alloys [3] and even hybrid joints metal-metal and metal-polymer joints [4]. Clinch joints are frequently utilized in automotive sub-assemblies [5], building components [6] or steel cases. In order to guarantee the required strength of clinched joints, several characterization tests have been utilized, e.g. tensile tests on H-shaped samples, shear tests, fatigue tests [5] and also impact tests [7]. Basically, two different clinching schemes are available today, a TOX type, which uses a grooved fixed die and a TOG-L-LOC type (also known as Eckold method) involving an extensible die [8]. Several studies have been carried out on the TOX configuration involving numerical simulations based on finite element methods for analyzing the effects of the tools geometry on the joints strength [9]. Generally, both the clinching joint formation and the separation of sheets are simulated for such a purpose. The latest works on the subject have been focused on the optimization of the clinching tools geometry for the increase of the joint strength. An optimization method of the clinching tools using moving a least-square approach is introduced in [10], while an inverse approach for the identification of the clinching tools geometry is proposed in [7]. Although these methods have demonstrated to be able to determine the optimal geometry of the clinching tools within a reasonable number of iterations, they have been mainly applied for the optimization of the clinching tools for a restricted couple of sheets. By contrast, the em-

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Selection and peer review under responsibility of Professor Roberto Teti
doi:10.1016/j.procir.2013.09.029

ployment of extensible dies permits to join a series of sheets having a wide range of thicknesses with a single set of clinching tools, since the die, which is composed of two or more sectors can spread radially. Thus, an optimization of the clinching tools for a range of sheets thicknesses would be more beneficial in several fields, such as the assembly of steel cases and components used in civil applications, where a frequent change of the clinching tools would severely increase the run time.

In this study, a numerical model of the clinching joint formation using an extensible die is developed by a finite element method and the influence of the process parameters is analyzed through the employment of design of experiments and a statistic approach. The FE model involves the simulation of both the clinch joint formation and the characterization of the joint. A design of experiments approach is involved to highlight the effect of the process parameters, i.e. the tools geometry and the sheets thickness on joint profile. Attention was paid to the main clinch geometrical characteristics that are the neck thickness and the undercut. Thus, the optimal configuration of the clinching joint was found by developing a flexible expert system based on an artificial Neural Network and a Genetic Algorithm.

2. Methodology

The first part of the proposed method involves the development and the validation of a finite element model and by simulating the clinching process under different processing conditions. To this end, a design of experiments approach, based on a Taguchi's orthogonal array, was involved to reduce the number of simulations. The second part of the proposed methodology is based on the development, the training and the validation of an artificial Neural Network (ANN) model in which the predictions of the FE simulations are used as the training and the validation data sets. The ANN is utilized to interact with an optimization tool (OT) rather than a direct connection between the FE modeling and the OT, as well as in [10], for two reasons: (1) the simulation time is significantly longer than the optimization tasks, thus its implementation within the optimization procedure would represent the bottleneck of the OT, and (2) the employment of the ANN allows to analyze several design solutions in fewer time. Indeed, after the network training and its validation, the network can be reused to analyze other design solutions and objective functions without requiring further FE runs.

A series of preliminary experimental tests were conducted using an extensible die configuration in order to calibrate and validate the FE model. The extensible dies (ED) are constituted by a fixed die anvil and a series of die sectors that can slip radially. Such radial motion is partially constrained by a rubber spring as depicted in Fig. 1. A Jurado clinching machine model Python is used to conduct the experimental tests. The geometrical characteristics of the clinching tools are: the punch diameter d = 4.0 mm; the die anvil diameter D = 5.0 mm; the die depth h = 1.1 mm. AISI 1010 sheets with nominal thickness of 1.0 mm were used in the experiment tests. The mechanical properties of the sheet material were determined by performing a series of tensile tests on sheet samples designed according to ASTM E08 M-04 for sheets characterization with a gauge length of 50 mm. The material characteristics are reported in Table 1.

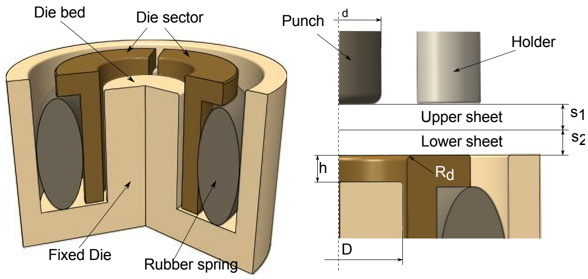

Fig. 1 Schematic representation of clinching tools with extensible die.

Table 1 Mechanical characteristics of AISI 1010.

Mechanical behavior	Value
Young Modulus [GPa]	210
Poisson's ratio	0.3
Ultimate tensile strength [MPa]	320
Initial yield stress, σ_0 [MPa]	88
Fitting function used in FE modelling with parameters obtained from stress-strain curves	$\sigma_{eq}= K\ \varepsilon^n$
K [MPa]	364
n	0.27

2.1 Design of Experiments

Design of experiments was adopted to define the simulation plan according to the involved process parameters. A L27 Taguchi's orthogonal array was utilized to investigate the effect of five design factors over three levels. Thus, the higher order interactions were neglected to reduce the number of the simulations trials. The parameters considered in the analysis were: the punch diameter (d), the wall clearance (D - d)/2, the die bed depth (h), the corner radius of the die sectors (Rd) and the sheets thickness, which was assumed to be equal for both sheets ($s = s_1 = s_2$). The remaining process conditions, that are the punch corner radius (0.2 mm) and the pressure on the holders (500 N) were kept constant among the simulations. Each parameter had three levels, as reported in Table 2, which were chosen to cover a relatively wide range of combinations.

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