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Finite Element Simulation of Punch Shear during Hole Piercing in Auto Chain Components

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ABSTRACT:

The capabilities of presses are sometimes limited due to larger cutting force requirement for some sheet metal operations. Reducing the tonnage requirements for such operations will sometimes make the presses capable of doing such operations. FEM simulation can be a reliable tool in predicting the amount of tonnage required for the metal stamping operation. An attempt is taken in this study to analyse the behaviour of the hole piercing operation in an automobile chain part using DEFORM 3D software. The main focus is on the prediction of tonnage requirement with different shear methods on the piercing. Simulations were conducted with flat, single sheared, double sheared, reverse double sheared, convex sheared and concave sheared punches and analyzed for variations in the press load. The phenomena of piercing are also observed through the simulation based on AISI 1060 steel component used for automobile chain as inner plate. Simulation results showed that the shear angles provided on piercing punches will reduce the punch load significantly.

KEYWORDS:

Automobile chain; Hole piercing; DEFORM 3D; Finite element simulation; Shear on punch

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1. Introduction

Metal stamping is the process of producing components of required shape and size from sheet metal in mass production. These stamping operations use a press comprising punch tool and die surface forms the metal into the required component. These tools produce the components from either continuous coil stock or individual unit stock sheet metal. Blanking and piercing are the basic sheet metal cutting operations. While producing components by blanking and piercing operations some amount of material cut-out from the stock material sheet used. If the cut-out portion of the stock material is the required product, the process is called as blanking. If the cut-out portion is the scrap, the process is called piercing. Though the blanking and piercing operations look similar, there is distinct difference in their terminologies and applications. In blanking and piercing operations the stock material is forced into the die opening by the punch to make the cut. When the force transmitted through the punch is high enough to exceed the shear strength of the stock material, the material continues to yield until complete fracture occurs and the component is cut into the required shape.

It is not always possible to do sheet metal cutting operations in any press. The rated capacity of the press decides the ability of the press to perform the selected sheet metal operation in it. Hence the cutting force requirement for any sheet metal cutting operations should be well below the rated capacity of the press on which the operation to be performed. If the estimated cutting force is above the rated capacity of the press, the industries are to look for other options. One amongst them is reducing the cutting force requirement for the component by providing shear on the punches. Punch shear angles not only reduce the cutting force requirement by the scissor action, but also reduce the press tonnage by reducing the area of contact during shear at any point of time. Punch shear is also expected to reduce the press shocks and facilitate smooth cutting. As shearing has the tendency to distort, the stock metal shear angle will be given on die for blanking operation and on punch for piercing operation.

Simulation of the sheet metal cutting operations will help to estimate the required shear angle for punches and towards deciding the capability of the presses to perform the sheet metal cutting operations. Finite Element Method (FEM) is becoming a popular and reliable tool in simulating and optimizing the metal forming process. FEM helps in analyzing the material flow, analyzing the defects and estimating die stresses, loads and optimizing process parameters. But for sheet metal cutting operations like blanking and piercing, FEM is less mature. The experiments conducted towards the effects of sheared punches on cutting forces proved that the cutting force is reduced by providing sheared punches compared to the traditional flat punches [1]. The punch force during blanking at low speed in both experiments and simulations compare very well [2]. FEM simulations can be helpful in determining the process parameters, which can improve the quality of the blanked work piece [3]. Finite Element Analysis (FEA) of the shear punch testing is carried out. The simulation results are compared and validated with experimental data for different materials. The shear yield stress estimated by FEA compares well with the experimentally determined shear yield strength [4]. FEM simulations were conducted by varying the punch and die clearances and the results were in excellent correlation with the actual experiments [5]. Using FEM simulations, the optimum punch-die clearance is selected for different part radii to obtain more uniform punch wear using DEFORM 2D/3D [6]. Various authors conducted FEM simulations for metal stamping process. However, there is lot of scope for FEA of piercing operations.

The aim of this work is to simulate the hole piercing operation in manufacturing of auto chain plates and to analyze the effects of various punch shear methods on cutting force and other parameters of the piercing operation. In this paper the three dimensional finite element simulation of hole piercing operation using DEFORM 3D software is discussed. The effects of varying shear angles in punches on the cutting force and shear stress during the piercing process also analyzed. The effects of shear methods namely single shear, double shear, inverted double shear, convex shear, concave shear punches and staggered punches on cutting force and shear stress were compared with that of flat piercing punches. The outcome of this work would be beneficial in estimating the punch shear to suit the available press capacity.

2. Modelling and FEA

2.1. Modelling for hole piercing process

The component chosen for the piercing simulation experiments are of AISI 1060 inner plate (3.6mm thickness) used in automobile chain assembly as shown in Fig. 1. This experiment begins with the 3D modeling of the blank, punches, die and blank holder then import them in STL format in DEFORM 3D software. The dimensions of the component before and after piercing are shown in Fig. 2. The dimensions of the punch used in the simulation experiments are shown in Fig. 3.

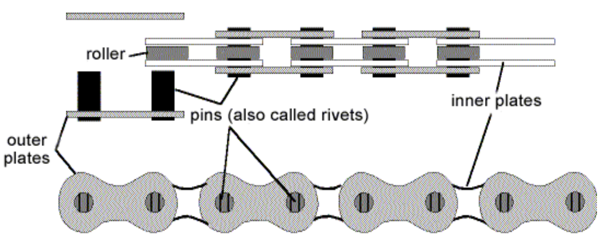


Fig. 1: Parts of a chain assembly

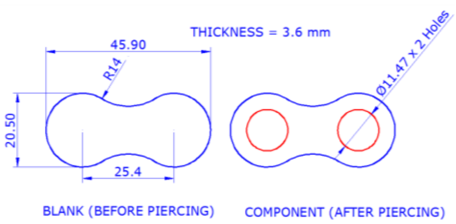


Fig. 2: Dimension of the simulated component

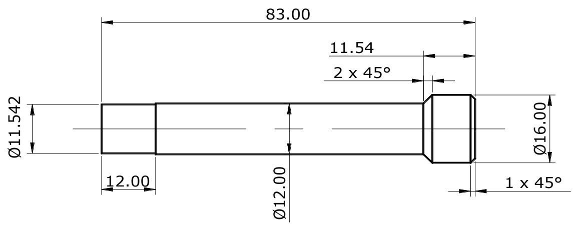


Fig. 3: Dimensions of the piercing punch

For this simulation, the die opening size was chosen as 11.65mm diameter. Fig. 4 shows the FE models of the tool consists of blank (work piece), punch holder, piercing punches, bottom die and blank holder used for the simulation of the piercing process in DEFORM 3D Software. Various shear angles and shear methods are made in the piercing punch models before beginning the experiments. The models of the blank, die and blank holder are kept common for all the experiments. To assess the effects of varying shear angles on the punches, models of single sheared punches with shear angles of 5°, 10° and 15° were created for the simulation experiments as listed in Table 1.

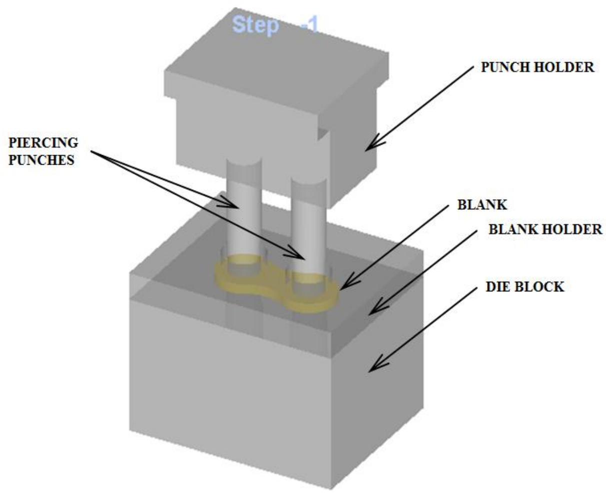
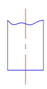
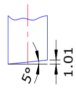
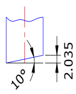
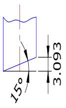


Fig. 4: FE model setup used for the simulation experiments

Table 1: Punch shear angles (single shear) and height of the shearing

Type	Punch tip profile	Shear angle	Height of shearing (mm)	Height of shearing (times of blank thickness)
SS-0		0° flat punch	- flat punch	-
SS-5		5°	1.01	0.28
SS-10		10°	2.035	0.56
SS-15		15°	3.093	0.86

To compare the effects of sheared punch and punch staggering methods with that of flat punch, models of punches were created as listed in Table 2. To compare the effects of double sheared punch, inverted double sheared punch, convex punch and concave punches with that of flat punches, models of punches were created as listed in Table 3.

Table 2: Single shear and staggered punches used in the simulation experiments

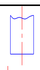
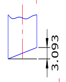
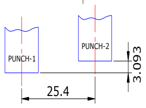
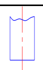
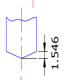
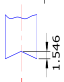
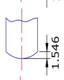
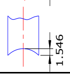
Type	Punch tip profile	Shear angle	Height of shearing (mm)	Height of shearing (times of blank thickness)
SS-0		0° flat punch	Flat punch	-
SS-15		15°	3.093	0.86
PS-15		Staggered punch	3.093	0.86

Table 3: Double shear (ds-v), inverted double shear (ds-iv), convex (cv) and concave (cc) shear methods used in the experiments

Type	Punch tip profile	Shear angle	Height of shearing (mm)	Height of shearing (times of blank thickness)
SS-0		0° flat punch	Flat punch	-
DS-V-15		15°	1.546	0.43
DS-IV-15		15°	1.546	0.43
CV-15		15°	1.546	0.43
CC-15		15°	1.546	0.43

2.2. Simulation of hole piercing process

The parameters shown in Table 4 are used for simulating the punching process. The pre-processor module of the DEFORM 3D software performs three important tasks. In the input module of the software, the models and the process conditions are introduced. The automatic mesh generation program of the software creates a mesh taking various parameters into consideration. The software also consists of an interpolation module for interpolating the deformation history of the old distorted mesh into the newly generated mesh.

Table 4: Simulation parameters for the piercing experiments

Parameter	Value
Object type	Work piece : Plastic Punch/Die/Blank holder: Rigid
Shape complexity	Moderate
Accuracy level	Accurate
Number of elements	46,584
Cutting speed	25 mm/sec
Total primary die travel	11 mm
Friction co-efficient	0.08

Automatic remeshing makes it possible to perform continuous simulation without user intervention. The simulation is started in the simulator module after inputting all necessary parameters in the pre-processor module. The simulation can be paused in between to facilitate checking correctness of the process. The post processor module is used to view the results of the simulation. Fig. 5 shows the meshed model of the auto chain component used for the piercing experiments. The automatic mesh generation feature of the DEFORM 3D is used for the mesh generation. Fig. 6(a) shows the zones of the standard sheared edge which clearly indicates the various zones. Fig. 6(b) shows the sheared edge of the simulated pierced component, which is very similar to the standard shear edge.

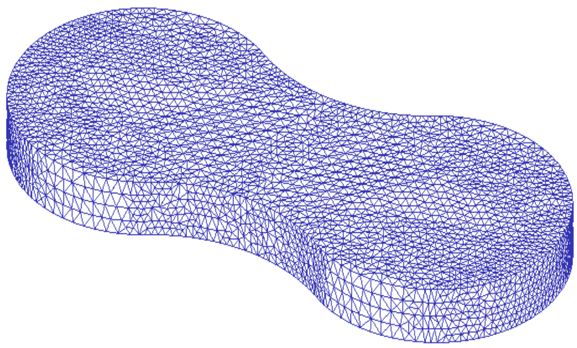


Fig. 5: Meshed blank model

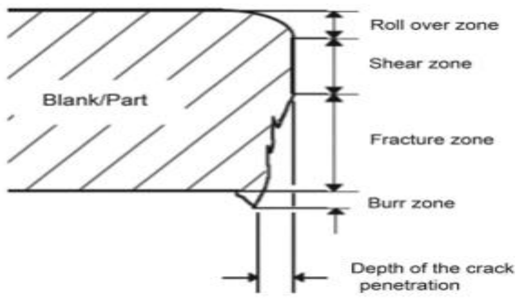


Fig. 6(a): Zones of the standard sheared edge

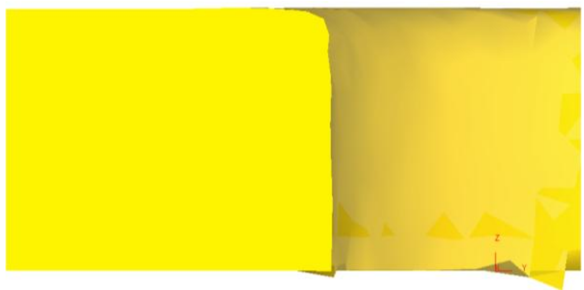


Fig. 6(b): Sheared edge of the simulated blank

The post processor of the DEFORM 3D software is used to analyse the material flow during piercing, the fracture, load and stress values. Fig. 7 shows the material flow pattern during piercing by different shear methods used in this simulation experiments. The post processor module of the DEFORM 3D software is helpful in analyzing the shearing phenomenon happening while using various shear methods. The punch shape will decide the shape of the slug produced. Fig. 8 shows the slugs sheared from the blank material for various shear methods.

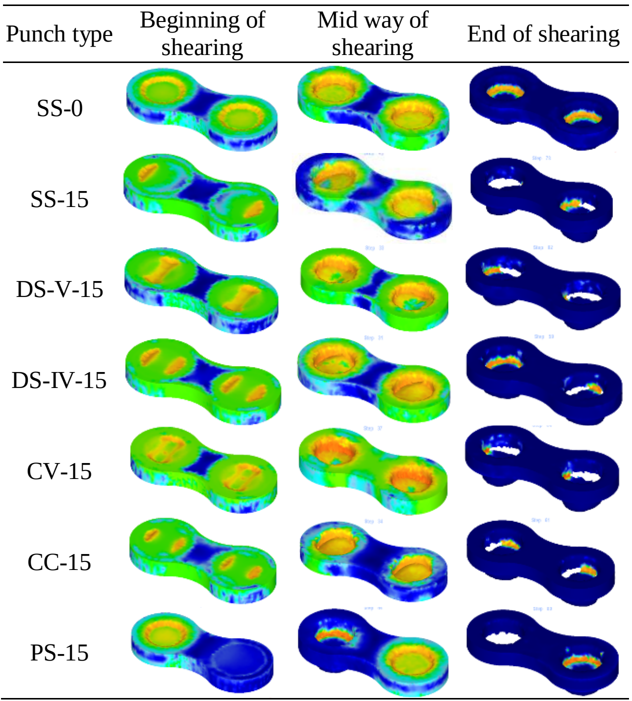


Fig. 7: Comparison of stress distribution between piercing with flat punch and other shear methods

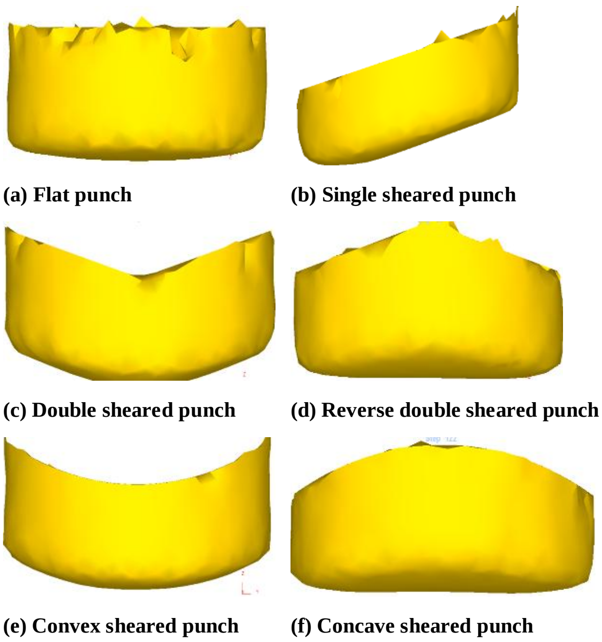


Fig. 8: Slugs sheared from blanks for various shear methods

3. Results and discussions

3.1. Effect of punch shear angle on cutting force

The results of the piercing simulation experiments inferred that the punch load is decreasing for an increase in the shear angle. The reduction in punch load is in the order of 4%, 6.3% and 17% respectively for 5°, 10° and 15° single sheared punches when compared with flat punches. From Figs. 9(a-b), it is evident that the maximum punch load is decreasing as the punch shear angle increases. Compared to the flat punches, the punch loading is spread to a lengthier stroke as the punch shear angle increases.

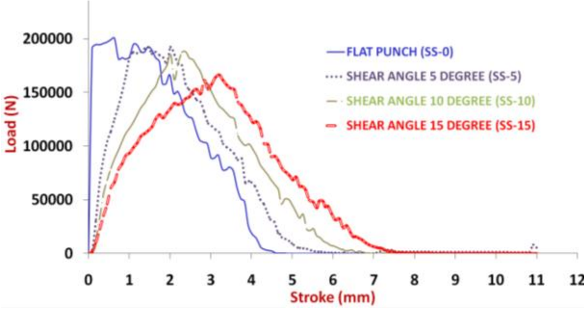


Fig. 9 (a): Force vs. Displacement for single sheared punches

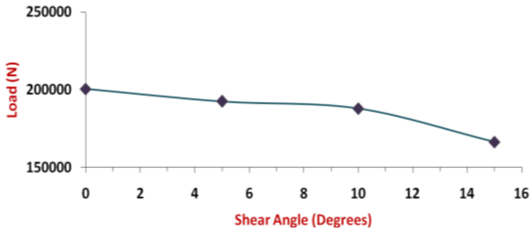


Fig. 9 (b): Effect of shear angle on punch loading

3.2. Cutting force requirement for single sheared punch and punch staggering method

The maximum punch load for staggered punches and single sheared punches are reduced as much as 35.3% and 17% respectively when compared with that of the flat punches as shown in Fig. 10(a). The lowest punch load between the top and bottom extreme ends of the punch stroke has initially increased and then reduced to as low as 80% of the maximum punch load for flat punches as only one punch is engaged in the piercing process and subsequently the punch load increasing as both punches are on shearing. The effective stress curve obtained clearly indicates that the stress is spread to almost entire stroke length, unlike in the case of flat punches where the shear stress dropped rapidly as shown in Fig. 10(b).

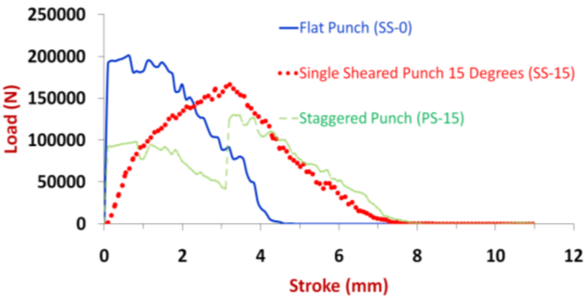


Fig. 10(a): Force vs. Disp. for single sheared & staggered punches

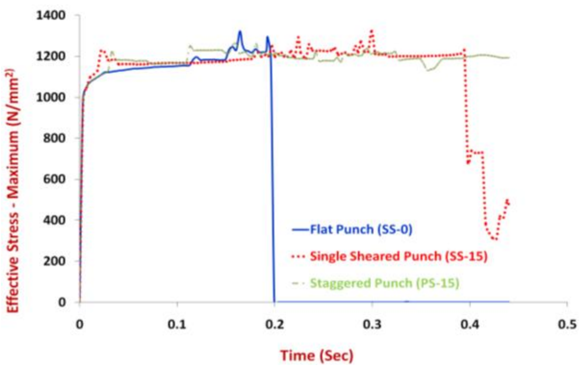


Fig. 10(b): Effective stress

3.3. Cutting force requirement for punch shear methods

The maximum punch load for other shear methods tested are reduced when compared with that of the flat punches as shown in Fig. 11(a). The effective stress curve obtained for these methods clearly indicates that the stress is spread to almost entire stroke length, unlike in the case of flat punches where the shear stress dropped rapidly as shown in Fig. 11(b). The values of punch loads are listed in Table 5.

Table 5: Maximum punch load for various shear methods

Type of punch	Max. punch load (N)
Flat punch	2,00,583
Double sheared punch	2,02,085
Inverted double sheared punch	1,92,089
Convex sheared punch	1,94,029
Concave sheared punch	1,89,067

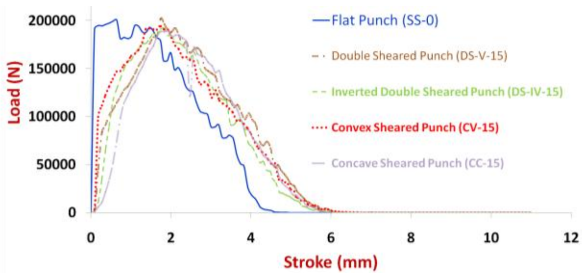


Fig. 11(a): Force-Displacement Diagram for Other Shear Methods Simulated

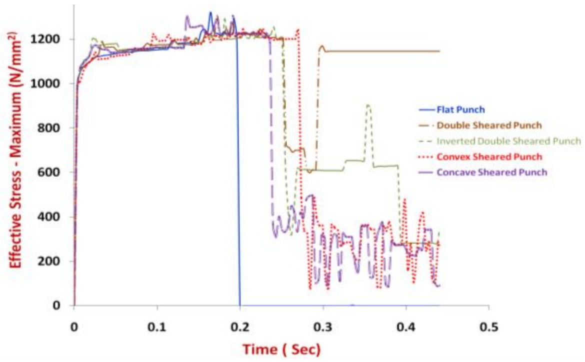


Fig. 11(b): Effective stress for other shear methods simulated

4. Conclusion

This work is a step forward in finding a solution to the material flow related analysis in piercing operation. The material flow and the shearing phenomenon of the piercing operation were very well simulated and analysed using DEFORM 3D in this work. The present work established that the provided shear angles on piercing punches reduced the punch load and the shear angles on punches reduced the effective stress during the piercing operation. The effects of varying punch shear angles on the dimensional features of the component produced and shape of the components are to be analyzed in the future work.

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