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An Overview of Optimization Techniques Utilized in Sheet Metal Blanking Processes

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Abstract: *This research examines various methodologies employed to predict optimal parameters in the sheet metal blanking process and optimize these parameters. It thoroughly investigates the different parameters that influence the process's output and analyses their impact on the quality of the blanked material through diverse methodologies. The findings of the study confirm the efficacy of each methodology utilized for parameter optimization.*

Keywords: Blanking, Burr, Clearance, Optimization

I. INTRODUCTION

Blanking is a commonly employed technique in high-volume production. Over the past two decades, researchers have extensively investigated the blanking process. Empirical guidelines for process variables, including punch and die radius, speed and clearance have been established through blanking experiments conducted on planar or axisymmetric configurations. Despite these efforts, a comprehensive understanding of the blanking process remains elusive.

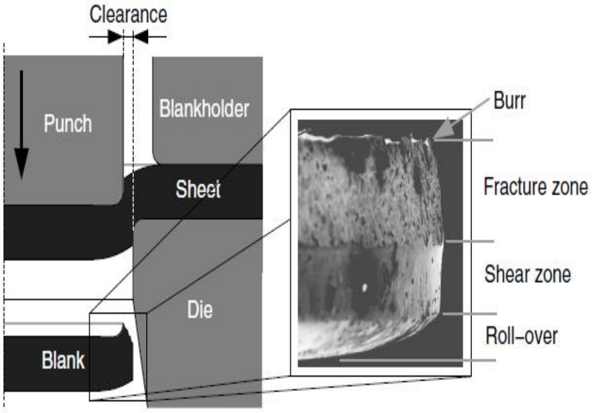

Figure 1: An illustration of the blanking method with different zones defining the product shape [2, 3, 4]

One of the primary challenges in numerical analysis lies in accurately describing the initiation of ductile fracture, which significantly influences the final product shape. Ductile fracture in metals is known to occur through the initiation, growth, and coalescence of voids. Voids can initiate at inclusions, secondary phase particles, or dislocation pile-ups. Previous studies, using numerical simulations, have shown that voids can even initiate at inclusions under large hydrostatic pressures during shear deformation. The growth and coalescence of voids are driven by plastic deformation. As a result, the modelling of ductile fracture initiation necessitates consideration of the deformation history.

In this paper, the authors employ local ductile fracture criteria that incorporate the stress and strain history to predict the initiation of ductile fracture. These criteria can be expressed as an integral over equivalent plastic strain, representing a certain function of the actual stress state reaching a threshold value. The function f(s) is related to the invariants of the Cauchy stress tensor (J1, J2, and J3). In the blanking process, this initiation directly affects the height of the shear zone and, consequently, the shape of the blanked edge.

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The different formulations of these criteria include parameters that influence ductile fracture, such as plastic strain and triaxiality (defined as hydrostatic stress divided by equivalent von Mises stress: sh = s). It is well-known that hydrostatic pressure delays ductile fracture initiation due to its effect on void initiation and growth. Therefore, triaxiality is often incorporated in the function f(s). Significant plastic strains allow voids to grow and coalesce, justifying the integration over plastic strain.

In model formulations, the critical value C is typically considered a material constant. Experimental characterization is necessary to determine the value of C, after which the criterion can be applied to different situations. However, existing ductile fracture criteria in the literature have not provided examples where the critical value C is determined under loading conditions different from the actual application. In other words, these criteria demonstrate success when both characterization and application occur under similar loading conditions. This implies that the parameter C somehow encapsulates information about the loading path.

II. OPTIMIZATION

The optimization process of sheet metal blanking parameters involves a comprehensive analysis of the desired output, which can include the following objectives:

- Minimizing the total cost of producing a component.
- Enhancing the quality of the product.
- Reducing the in-process time of the component, among others.
- During the optimization process, the operator may seek to minimize or maximize the objective function based on the specific goal.
- Several factors influence the output of the sheet metal blanking process. These factors include blank holder force, clearance, thickness, material properties, friction, tool geometry, blank layout, speed or stroke rate, and punch die alignment. Among these parameters, the first four are considered controllable factors, while the rest are considered noise factors.

III. OPTIMIZATION TECHNIQUES

Design of Experiments:

Design of Experiments (DOE) is a systematic approach used to optimize process performance and acquire knowledge. Traditionally, the one-factor-at-a-time approach has been used, where a single factor is varied while keeping others constant to observe the response. However, this method is inefficient as it does not account for interactions between factors and often yields inaccurate effect estimates. DOE techniques, on the other hand, allow for a more comprehensive analysis of factor interactions and provide more accurate estimates of effects, leading to improved process optimization.

Finite Element Method:

The Finite Element Method (FEM) is a numerical simulation technique used to analyze problems related to sheet metal forming processes. FEM simulations can aid in the design of the process by reducing the number of trial steps required. While FEM simulation is widely used in various forming operations, there is currently no commercially available FEM code capable of accurately simulating the blanking process and fracture formation.

Neural Network Analysis:

Neural network analysis involves using neural networks as numerical devices to replace the need for a finite element code in predicting the optimum clearance of the sheared part. The input data for the neural network consists of material properties such as elongation, and the output data is the predicted optimum clearance. By training the neural network with appropriate data, it can effectively estimate the optimum clearance without the need for extensive finite element simulations.

Genetic Algorithm:

Genetic algorithms are optimization algorithms that evolve a population of candidate solutions toward better solutions. Each candidate solution, represented as a set of properties or chromosomes, undergoes mutation and recombination to generate a new population in each generation. The fitness of each individual is evaluated, and the more fit individuals are selected to form the next generation. The algorithm terminates when a maximum number of generations is reached or when a satisfactory fitness level is achieved. Genetic algorithms are often used to solve complex optimization problems where traditional methods may struggle to find the global optimum. They can handle various representations, including binary strings or other encodings, and can be applied to problems with fixed-size or variable-length representations.

Overall, these methodologies, including Design of Experiments, Finite Element Method, Neural Network Analysis, and Genetic Algorithm, offer valuable tools for optimizing sheet metal blanking processes and improving process performance.

IV. LITERATURE REVIEW

The process of identifying influential parameters in the blanking process involves conducting a comprehensive literature review to gather information from various sources. Articles from reputable journals and research platforms such as ScienceDirect, IEEE, Emerald, and Springer Link were collected, along with free articles available on the internet. The literature review focused on journal papers and conference papers related to press tool works and parameter optimization.

Faura et al. (1998) proposed a methodology to obtain optimal punch-die clearance values using Finite Element Method (FEM) simulations. They studied the shearing mechanism by simulating the blanking operation and utilized the Croockcroft and Latham fracture criterion. The optimal clearance was determined based on the coincidence of crack propagation direction with the line joining the points of crack initiation in the punch and die, resulting in clean blanked surfaces.

Maiti et al. (2001) evaluated the influence of tool clearance, friction, sheet thickness, punch/die size, and blanking layout on sheet deformation during the blanking process. They conducted Finite Element Analysis (FEA) using the ANSYS package, observing the effects of clearance and friction on blanking load and stress distribution in the sheet.

Fang et al. (2002) studied the optimization of punch-die clearance values using a finite element technique. The research focused on the influence of clearance on the structure of blanked surfaces and its impact on die life, blanking force, unloading force, and dimensional precision.

Hambli (2002) conducted experimental investigations on the blanking process using tools with different wear states and clearances. The aim was to study the effects of clearance, tool wear, and sheet metal thickness on blanking force and the geometry of the sheared profile. The study utilized the Design of Experiments (DOE) method to model and analyze the relationships between process variations. The results highlighted the interactions between controllable factors (clearance) and noise factors (wear and thickness), making the process more robust against variations in tool wear and sheet thickness.

Hambli et al. (2003) investigated the influence of clearance, tool geometry, and workpiece material properties on the blanking process and structure of the blanked surfaces. They utilized axisymmetric blanking simulations and a damage model to describe crack initiation and propagation. The results demonstrated that the optimal clearance varied depending on the material elongation, with no universal value applicable to all situations.

Ridha (2005) presented a software called BLANKSOFT for optimizing sheet metal blanking processes. The program predicted various parameters such as sheared profile geometry, mechanical state, burr height, force-penetration curve, and punch wear evolution. The software incorporated factors such as material properties, product geometry, and tool wear.

Emad and Ibrahim (2008) developed a model to analyze the effects of various parameters on the blanking process. They employed a combination of Finite Element Method (FEM) and Design of Experiments (DOE) techniques to optimize the sheet metal blanking process. Experimental levels were defined for factors such as clearance, blank holder force, and sheet metal thickness. The study compared the results obtained from FEM simulations and DOE, ultimately determining the proposed optimal set of parameters.

R.S. Mohan Kumar (2017) A Knowledge Based System is proposed for selecting optimum parameters in blanking die design. The system utilizes rule-based AI approach, integrating AutoCAD and Auto LISP for automation. Four modules address dimensional tolerances, fine-blanked parts, and trimming allowances. Information from standards, catalogs, and industrial practices is incorporated. The flexible system generates optimal parametric outputs based on input conditions and can be adapted to specific shop floor requirements and technological advancements. A demonstration of the system's application is showcased using real-time industrial components.

Phyo Wai Myint (2018) The selection of appropriate process parameters is crucial in achieving a fully-fine sheared surface in the fine blanking process. Researchers used the critical fracture criterion obtained from experiments to predict cut surface conditions. By utilizing clearance-dependent critical ductile fracture criteria and employing the Finite Element Method, they studied the influence of process parameters on the sheared surface length. The findings emphasized the effectiveness of the Oyane criterion for accurate and stable prediction of ductile fracture initiation in fine blanking.

Mohamed Sahli (2020) This paper focuses on the optimization of steel sheet metal blanking for automotive parts manufacturing. Numerical computations and experimental verification are conducted to analyze the influence of cutting process parameters on the stress state of cold-rolled steel sheets. The commercial code Lsdyna® is used for simulations, and a constitutive model is established based on material testing. The study aims to predict shear stress and plastic strain distribution during blanking, considering punch-die clearance and deformable punch. Finite element predictions show agreement with experimental results, with a margin of error of approximately 31%.

Overall, the literature review reveals that while some analytical techniques have been used to study the blanking process, further investigation and research are still required to fully understand and optimize the process.

V. DISCUSSION AND CONCLUSION

The study concludes that selecting the most effective methodology for optimization in sheet metal blanking is challenging due to various approaches available. Design of Experiments aids in identifying the optimal parameter combination. Finite element simulation provides the best tool setting for optimum process output. Neural network analysis requires costly and time-consuming training. Genetic algorithm technique employs mathematical formulas and algorithms to achieve optimal results.

In conclusion, the overview of methodologies used in sheet metal blanking optimization demonstrates a diverse range of techniques. Design of Experiments proves valuable in identifying optimal parameter combinations. Finite Element Method enables simulations to determine optimal tool settings. Although Neural Network Analysis requires costly training, it offers potential through artificial intelligence. Genetic Algorithm employs mathematical formulas for optimal results. Each technique presents its own strengths and limitations, requiring careful consideration in their application. Further research is needed to explore their suitability in various scenarios and to identify the most appropriate approach for specific optimization objectives in sheet metal blanking processes. The selection of the most effective methodology should be based on a thorough understanding of the requirements and constraints of the specific application.

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