IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X
PP 74-78
www.iosrjournals.org

A Review on FE Analysis, Simulation and Optimization of Sheet Metal Forming Process - A FE, DOE And Statistical Approach

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Abstract:*In Sheet metal forming process materials undergo permanent deformation by cold forming to produce a variety of complex three dimensional shapes. The process is carried out in the plane of sheet by tensile forces with high ratio of surface area to thickness. High rate of production and formability is determined by its mechanical properties. Methods of sheet metal processes such as stretching, shearing, blanking, bending, deep drawing, redrawing are introduced. Variables in sheet forming process were discussed together with formability and test methods. Defects occurring during the forming process will be emphasized. The solutions to such defect problems will also be given. the detailed of literature review is presented in this paper corresponding to the metal forming processes and the various methods used for the analysis and optimization for defect free process are explained. As lots of research is going in the field of material forming a systematic literature review based on the optimization technique and analysis is presented in the paper.*

Keywords: *DOE, FEA, optimization, sheet metal forming process, statistical methods,*

I. INTRODUCTION

Sheet metal forming (SMF) is one of the most common manufacturing methods for metal parts and is used widely in industries. Modern software programs are routinely used by industries to study the characteristics of and to reduce the cost of sheet metal parts that are used in automotive and other applications. Virtual simulations that are based on complex math models and state-of-the-art computational tools play a very important role in reducing the high costs associated with prototypes and the time to market the product [6]. Formability studies of a sheet metal part determine if a part is formable by changing the factors that affect its formability. Vibration (or modal) analysis is performed to determine the frequency and mode shapes of the component or the assemblies, With the advent of high-speed computer technology and simulation tools, many industrial establishments are using virtual manufacturing processes to predict formability of sheet metal components before prototypes and testing are performed. Typically, there will be 3–6 different stages of forming operations before a final product is made. Each forming stage involves separate die and punch tool set, that costs several thousands of dollars for careful manufacture and to assemble. With tens and thousands of sheet metal parts in a typical automobile (doors, roof, trunk lid, fenders, etc.), and for several car and truck models, billions of dollars are spent annually by the auto and other transportation industries. Reduction of cost and cycle time to manufacture these parts are of paramount importance leading to lot of research in innovative production and optimization methods involving modern light weight and strong materials for the car body panels. Forming characteristics such as thinning, rupture (or splitting), wrinkling, etc., can be predicted and controlled with high level of confidence using the CAE tools such as Abaqus/Explicit (Simula), AutoForm (Auto- Form Engineering), HyperForm (Altair Hyperworks), Dynaform/LS-DYNA (ETA/LSTC), Pam-Stamp (ESI Group), etc. The solid model geometry prepared in CAD modelers can be easily imported into meshing algorithms such as Hyper Mesh. The model is then usually exported to high end solvers such as Hyper Form (one-step) or LS-DYNA (incremental) to perform the analysis after which, the formability results can be displayed using a post processor such as Hyper View or LS-Pre Post. Application of design of experiments (DOE) procedures to study the inter-relation between the several forming parameters has been reported by many researchers. Both these methodologies have been used for several other applications within the design and manufacturing areas, the literature presented in this section is limited only to select references in the sheet metal forming area.

II. LITERATURE REVIEW

Lots of work is going in the sheet metal forming and numerous work is happened upto 2012-13 including optimisation techniques and use of computer aided modelling, simulation and manufacturing, a literature review is presented here,

Yudieski Bernal-Aguilar, José Roberto Marty-Delgado,et.al.,(2013) [1] carried out an investigation, and The main purpose of this work is to develop an intellectualized control technique on the deep drawing of square cup made of AISI 304 DDQ stainless steel using genetic algorithm. These control methods are employed in order to investigate the most significant parameters in sheet metal forming process such as drawing force, with a view of optimizing these parameters. The genetic algorithm was used for the optimization purpose to minimize the force of the deep drawing process and to investigate the roles of other parameters as blank holder force. Experimental results show that these combinations of control system can cover a wide range of both materials and influential forming parameters automatically. The results further confirm that the developed system is effective and valid alternative for quick responsible control system with high flexibility In this paper, effect of the most significant parameters in sheet metal forming process of a square cup, such as punch and dies radius, and their interaction on drawing force, is well analyzed with a view of optimizing this parameter. The present results show that the intelligent control in deep drawing of sheet metal can be successfully used in the field of parameters optimization. The present model can be useful in conducting parametric studies on the different parameters affecting the process including die design, process and material parameters.

L. Venugopal, M.J. Davidson, et. Al.,(2012) [2] have studied and applied the Taguchi method to find the optimum process parameters for maximum expansion of tube ends. The various process parameters namely the punch/die cone angle, the expansion ratio and the friction conditions are taken as the input process condition and the output; the maximum radial displacement is critically analyzed. Radial expansion is the increase in diameter of the tube by the die measured on the top most portion of the tube across its circumference. The optimal combination of the process parameters is obtained through the signal to noise ratio (S/N) analysis and the analysis of variance (ANOVA) methods. The parameters that affect the process are determined using Taguchi method and the most significant process parameters and their percentage contribution was determined by using ANOVA technique. Among all the three process parameters considered, it is found that the most significant factor is the die cone angle (α) and this factor contributes 43.56% on the total output response value while expansion ratio rp/r0 contributes 8.89% and the lubricant has contributed 38.59% on the total output. The experimental results are in acceptance with the predicted values for the 95% confidence interval and it is observed that the error is within the reasonable limit.

H. Arfa & R. Bahloul et.al., (2012) [4] in their investigation, the tool forces required to deform plastically the sheet around the contact area was discussed. The effect of the blank thickness and the tool path on the punch load and the deformation behaviour is also examined with respect to several tool paths. Furthermore, the force acting on the travelling tool is also evaluated. Similar to the sheet thickness, the effect of wall angle and part geometry on the load evolution, the distribution of calculated equivalent plastic strain and the variation of sheet thickness strain are also discussed. Experimental and numerical results obtained allow having a better knowledge of mechanical and geometrical responses from different parts manufactured by SPIF with the aim to improve their accuracy. It is also concluded that the numerical simulation might be exploited for optimization of the incremental forming process of sheet metal. Single point incremental forming is a method used for the manufacturing of the sheet metal products and brings new opportunities in the field of sheet metal forming as shown in the paper.

HOU Ying-ke et.al., (2010) [5] made an attempt to investigate the galling failure in SMF operations under different conditions via finite element analysis and experimental tests. A further objective was to develop a numerical methodology to study the galling failure problem in SMF processes. Major factors that influence the galling failure, including material properties of the sliding couples, process parameters and frictional coefficient are modeled in finite element analysis (FEA) model. A methodology using finite element analysis has been developed to investigate the galling problem in SMF processes. The accuracy and reliability of the methodology is validated by the experiment.

G. L. Damoulis & E. Gomes et.al., (2009) [7] have done sheet metal forming analysis and optimization trough the use of optical measurement technology to control spring back. The use of optical measurement equipment and software based on photogrammetric is becoming more affordable and is increasing their reliability in presenting results on surfaces topography as well as strain distribution. The question is, how feasible can their support be to the process/product development engineer in the choice of the right auto body-in-white (BIW) component design; how can they influence blank and tool geometries, process parameters and moreover the right material selection, in order to reduce the spring back of such materials on drawing, reaching the required quality standards for the part. This paper describes some industrial cases on how these new techniques can be applied to lay out industrial deep drawing processes, accomplished by the use of optical measurement, improving design and process issues.

R. Aerens & P. Eyckens & A. Van Bael & J. R. Duflou (2009) [8] have established practical formulae allowing to predict the forces occurring during the single point incremental forming process. This study has been based on a large set of systematic experiments on the one hand and on results of finite elements modeling simulations on the other. This led to analytical formulae allowing to compute the three main components of the force for five selected materials in function of the working conditions (sheet thickness, wall angle, tool diameter, and step down) with a good precision. Moreover, a general model has been deduced, allow computing an approximate value for the force for any material, based on knowledge of the tensile strength only.

Shiwen Wang & Weimin Zhuang et.al, (2010) [9] have simplified 2D FE analysis coupled with a crystal viscoplasticity model has been used in this study. Grains, their distributions, and their orientations were generated automatically based on probability theories using the developed VGRAIN system. For the same control parameters, average, maximum, minimum grain sizes, and distribution patterns were in either regular or non-regular distribution. Four microstructures of the UTMS were generated based on the gamma distribution. Up to six grain orientations are assigned randomly to each grain structure. Thus, a large number of FE analyses have been carried out based on the variation of grain structures and orientations. These were used to investigate the effect of grain size and orientation on the scatter of spring back values in the forming of UTMS channel parts.

J.F. Carvalho, P.S. Cruz , R.A.F. Valente and A. Andrade-Campos (2008) [10] carried out the simulation of metal forming processes using the Finite element method (FEM), which opens doors to solving new and more complex problems using alternative approaches, such as inverse methodologies/problems. In this paper two types of inverse problems were presented and discussed: the parameter identification and the shape optimization problems. The aim of the first type of problems is to evaluate the input parameters for material constitutive models that would lead to the most accurate results compared to physical experiments. The second category involves determining the initial geometry of a given specimen in order to provide the desired final geometry after the forming process. The purpose of this work is to formulate these inverse problems as an optimization problem and introduce a straightforward methodology of process optimization in metal forming. To reach this goal, an integrated optimization approach, using a finite element code together with a numerical optimization program, was developed. A gradient-based optimization method was employed as a combination of the steepest-descent method and the Levenberg-Marquardt techniques. Numerical applications are presented in the parameter optimization category, namely, the characterization of a non-linear elastic-plastic hardening model and the determination of the parameters for a non-linear hyperelastic model. It is also discussed the simultaneously identification of both constitutive material model parameters and the friction coefficient parameters. From the point of view of shape optimization problems, some examples are also shown and discussed such as the determination of the initial geometry of a specimen in an upsetting bill problem and a methodology for the square plate with central cut out problem. The final results for both categories are satisfactory, being proved that this kind of algorithms have great potential for future developments in more demanding and realistic benchmarks.

M. H. A. Bonte · A. H. van den Boogaard · J. Huétink (2008) [11] in their investigation Used finite element (FEM) simulations for processes. More recently, coupling FEM simulations to mathematical optimisation techniques has shown the potential to make a further giant contribution to product improvement and cost reduction. Much research on the optimisation of metal forming processes has been published during the couple of years. Although the results are impressive, the optimisation techniques are generally only applicable to specific optimisation problems for specific products and specific metal forming processes. As a consequence, applying optimisation techniques to other metal forming problems requires a lot of optimisation expertise, which forms a barrier for more general industrial application of these techniques this paper overcome this barrier by proposing a generally applicable optimisation strategy that makes use of FEM simulations of metal forming processes. It consists of a structured methodology for modelling optimisation problems related to metal forming. Subsequently, screening is applied to reduce the size of the optimisation problem by selecting only the most important design variables. Finally, the reduced optimisation problem is solved by an efficient optimisation algorithm. The strategy is generally applicable in a sense that it is not constrained to a certain type of metal forming problem, product or process. Also, any FEM code may be included in the strategy. Furthermore, the structured approach for modelling and solving optimisation problems should enable non-optimisation specialists to apply optimisation techniques to improve their products and processes. The optimisation strategy has been successfully applied to a hydroforming process, which demonstrates the potential of the optimisation of metal forming processes in general and more specific the proposed optimisation strategy.

G Lin, K Iyer, S J Hu, W Cai, and S P Marin (2005) [13] Used a two-dimensional finite element model, this paper presents a design-of-experiments (DOE) and the relationships between important hemming process parameters and hem quality for aluminium alloy AA 6111-T4PD flat surface–straight edge hemming. The quality measures include roll-in/roll-out of the hem edge as well as the maximum true strain on the exposed bent surface. The finite element (FE) model combines explicit and implicit procedures in simulating the three forming sub processes (flanging, pre hemming, and final hemming) along with the corresponding spring back (unloading). The results shows that the pre-hemming die angle and the flanging die radius have the greatest influence on hem edge roll-in/roll-out, while pre-strain and the flanging die radius impact the maximum surface strain significantly. The computational DOE results also provide the basis for process parameter selection to avoid hem surface cracking and particular insights for achieving acceptable formability Hemming is a three-step sheet-folding process utilized in the production of automotive closures. It has a critical impact on the performance and perceived quality of assembled vehicles. A hybrid finite element model is built for a flat surface– straight edge hemming simulation, with the mass scaling technique utilized to achieve computational efficiency. The results from the hybrid model with an appropriate mass scaling factor have been benchmarked against implicit outputs to ensure accuracy. The proposed model was also validated physically by comparing the FE analysis outputs to the experimental tests, obtaining acceptable agreements from both ends. Based on the validated model, a 16-run fractional factorial DOE is conducted to study the responses of the hem roll-in/roll-out and the maximum surface strain on the exposed hem surface. Among six input variables, pre-strain, flanging length, flanging die radius, clearance, pre-hemmer angle, and prehemmer path, the following variable effects were identified to be significant:

(a) The pre-hemmer angle and flange die radius on the hem roll-in;
(b) The pre-strain and flange die radius on the maximum surface strain;
(c) The pre-hemmer path having almost no impact on the roll-in/roll-out and maximum surface strain.

2.1Optimization techniques based on literature review:

2.1.1 Neural Network and Learning Vector Quantization Networks

A neural network is a massively parallel distributed processor that has a natural propensity for storing experiential knowledge and making it available for use. Also, nonlinearity and input/output mapping are the two most important benefits in the use of neural networks. Hence neural networks have been adopted to model the input/output relationship of non-linear and interconnected systems .The most common network used is back propagation (BP), which is essentially a stochastic approximation to non-linear regression.

2.1.2 Response surface methodology

One of the most widely used methods to solve this problem is response surface methodology (RSM), in which the unknown mechanism with an appropriate empirical model is approximated, being the function of representing a response surface model ,Usually to determine the optimum value of the process input parameters can mean to reach either the minimum or the maximum of a function that expresses these input parameters. Therefore, RSM is a good way to describe the process and to find the optimum value of the considered response .It concerns a set of mathematical and statistical tools that can be used to predict the response influenced by the considered input variables, in order to optimize this response .With RSM it is possible to define the relationships between the responses and the main controllable input factors, as well. As it is a powerful technique, when all independent variables can be measurable, Controllable and continuous along the experiment (with negligible error), the expression for the response surface can be $y = f(x1, x2\ldots\ldots\ldots)$

2.1.3Genetic Algorithm

Genetic Algorithm, introduced by Holland (1975), is a population-based search and optimization tool. The GA works equally well in either continuous or discrete search space. It is a heuristic technique inspired by the natural biological evolutionary process comprising of selection, crossover, mutation, etc. The evolution starts with a population of randomly generated individuals in first generation. In each generation, the fitness of every individual in the population is evaluated, compared with the best value, and modified (recombined and possibly randomly mutated), if required, to form a new population. The new population is then used in the next iteration of the algorithm. The algorithm terminates, when either a maximum number of generations has been produced or a satisfactory fitness level has been reached for the population. The fitness function of a GA is defined first. Thereafter, the GA proceeds to initialize a population of solutions randomly and then improves it through repetitive application of selection, crossover and mutation operators. This generational process is repeated until a termination condition is reached.

2.1.4Taguchi approach

Taguchi method is an efficient problem solving tool which can upgrade/improve the performance of the product, process, design and system with a significant slash in experimental time and cost. This method that combines the experimental design theory and quality loss function concept has been applied for carrying out robust design of processes and products and solving several complex problems in manufacturing industries. Further, this technique determines the most influential parameters in the overall performance. The optimum process parameters obtained from the Taguchi method are insensitive to the variation in environmental condition and other noise factors. The number of experiments increases with the increase of process parameters. To solve this complexity, the Taguchi method uses a special design of orthogonal array to study the entire process parameter space with a small number of experiments only. Taguchi defines three categories of quality characteristics in the analysis of (Signal/Noise) ratio, i.e. the lower-the-better, the larger-the-better and the nominal -the-better. The S/N ratio for each of process parameter is computed based on S/N analysis. Regardless of the category of the quality characteristics, a larger S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of process parameter is the level of highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) can be performed to see which process parameter is statistically significant for each quality characteristics. Taguchi method is one of the optimization techniques that could be applied to optimize input welding parameters. Optimization of process parameters is the key step in the Taguchi method in achieving high quality without increasing the cost. This is because optimization of process parameters can improve performance characteristics. The optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. This is particularly true when the number of the process parameters increases, leading to a large number of experiments have to be carried out. To solve this task, Taguchi method with a special design of orthogonal arrays can be used to study the entire process parameter space with a small number of experiments only.

III. CONCLUSION

As it has been observed from the survey that sheet forming process is a very promising manufacturing process which still requires further optimization. For the future, an extensive simulative campaign will be developed with the aim of investigating the effect of several process parameters combination, such as the initial sheet thickness, the tool path (in terms of vertical increment step size Δz), the tool diameter, the wall angle α on the characteristics of the parts (spring back, geometrical accuracy, forming limits, final thickness, punch load…). In this respect, the future research will focus on the application of an experimental design of in order to optimize the quality of the formed parts by an accurate control of the process parameters. More complicated shapes will be tried, based on the finite element analysis, in the future study. Of course, this opens perspectives for many further investigations in this direction, mainly focused on the experimental exploration of the proposed process and on the model extension to general geometries and materials. The application of computer-aided engineering, design, and manufacturing, CAE/CAD/CAM, is essential in modern metal-forming technology with the application of traditional and non traditional optimization techniques. Thus, process modelling for the investigation and understanding of deformation mechanics has become a major concern in research. The finite-element method (FEM) and optimization techniques have assumed increased importance, particularly in the modelling and optimization of forming processes.

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