Generative Design of Progressive Die

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***Abstract*—The evolution of products, dictated by the necessity to survive in the market, requires multi manufacturing processes to be performed simultaneously. Progressive die is one type of tool in which several individual stations are arranged in sequence. Each station will perform one or more various operations on the part. It is widely used to manufacture parts for automobile and other industries. This process with the help of progressive die is a very inexpensive method for forming moderate to large volume parts while keeping labor and die costs down. This study is dedicated to providing a 3D Computer-Aided Design (CAD) model for simple and economical progressive die construction which is suitable for the mass production of an industrial bracket. Different forces and stress convoluted in performing metal operations were also calculated with an appropriate formula. Generative designing technologies are also applied to yield the most efficient design economically as well as productively without compromising the optimum features of the tool. Various contours representation of data obtained is also presented in this work.**

***Keywords*—progressive die, generative design, stamping, industrial brackets**

I. Introduction

Sheet metal forming is an important process used to manufacture automobile, aerospace and other industries. Forming tools like punch and die are widely used in sheet metal forming operations like blanking, bending, punching and other operations. For complicated parts involving several operations, compound dies and progressive dies are used. A progressive die involves a sequence of forming operations at two or more stations to manufacture the part. Designing a progressive die is a complex and challenging task. Material selection is also very challenging for progressive die. This traditional method of designing is often tedious, manual and error prone. Moreover, there is lot of dependence on design expertise.

In the recent past, knowledge based tooling design system for design of progressive die is developed by various researchers. Computer aided design is employed in the design and modeling of progressive die. Automation of progressive die design is attempted by few researchers. Finite element method is employed to aid the design of progressive die by some researchers. Fuzzy logic reasoning, artificial intelligence systems and feature based modeling were some of the techniques employed to aid design of progressive die. It is found that little effort was taken to optimize the shape of progressive die. The objective of this paper is to optimize the shape of progressive die and minimize its weight using generative design.

II. Literature Review

Knowledge based progressive die design systems for stamping operations were developed [1]. These computers based progressive die design systems combines the experienced knowledge of human tool designers and conventional physical principles of progressive die design. With the sheet metal part input data given, an interactive computer program is developed which generates the flat geometry, generates strip layout, and selects punches, dies and other parts and 3D representation of the assembled progressive die.

Development of progressive die design automation system using computers is considered to be challenging and complicated [2]. Special methods were developed to represent work piece and forming tool shapes. There is a necessity to use the knowledge of tool making experts, and Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) resources to develop automatic die design packages. An automated progressive die design system is developed with twenty seven knowledge based modules [3]. Knowledge based system modules were created with the help of various production rules. The system module is designed in such a way that the user can interact with it conveniently. It is possible to automate important die design activities like checking the features of sheet metal components, Identification of progressive die parts, modeling of forming tools in progressive die. The knowledge based system module employs AutoCAD software and hence it is inexpensive and affordable to medium scale industries. The elements for construction low cost knowledge based die design systems were described in this study [4]. The coding of rules were carried out using AUTOLISP language. The developed die design system is user friendly and inexpensive.

The bulb shield provided in vehicle headlamp is usually produced by progressive die. This process is very challenging since multiple station progressive dies were

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used to form complex features of the head lamp bulb shield [5]. Surface distortion is a problem usually found in the forming of head lamp bulb shield. Finite element method is used to analyze the progressive forming of head lamp bulb shield. Finite Element Method (FEM) code DYNAFORMv5.2 is used to predict the results using simulation. The prediction made from FEM simulations agrees well with prototype tests. The basic causes of surface distortion in manufacture of bulb shields are identified in this approach. This methodology allows the forming problems to be found before physical forming tools are fabricated. Hence, the tooling try out time is minimized considerably in this approach.

The progressive die design of electron gun elements is quite complex and challenging due to accuracy requirements [6]. In the traditional progressive die design, manual error will take place. To solve this issue, there is a need of computer aided design of progressive die for forming of electron gun. C language is employed to develop this knowledge based CAD system. The data on the shape of the electron gun grid is given as input to the design system. The strip layout of the progressive die and assembly drawings were generated as output. The database of the die design system is built by interviewing die design experts.

An expert system using CATIA V5 was created in this study for designing drawing dies for outer panels for trunk lid and engine hood [7]. The knowledge based die design system accepts basic design information such as blank lines and dies surfaces as input and generates the final drawings of drawing dies. It was found out the entire design of drawing die is completed in one hour which is considerable less than the time taken in traditional die design. Drawing dies with high quality, design flexibility and low cost are the other benefits of using this automated die design system. The design and validation of progressive die was carried out using SOLIDWORKS software in this study [8].

It was found that a large amount of tool steel is consumed in the manufacture of a drawing die used in typical industrial operations [9]. A very hard material like tool steel is employed to make a drawing die. It is very challenging to shape tool steel in to complex die profiles. In this study, an attempt has been made to enhance the structural integrity of a notching die. A progressive die is designed for U bending process using DEFORM software in this study [10]. The die structure was developed in the next step. Selection of die materials and heat treatment is the next step. The model of scrap less multistage progressive die was created using IDEAS program. Part drawing was carried out in AutoLisp. Quality of drawing dies can be achieved by revision through try out.

The design and process planning of progressive die is quite complicated and knowledge intensive [11]. An intelligent process planning system for making die plates was established. Production rules and heuristic representations were combined.to represent relationship in the process planning of progressive dies. A computer aided design and computer aided manufacturing system was developed to for the blanking or piercing of complicated shaped sheet metal parts [12]. The CAD system is capable of verifying the manufacturing viability of parts using Auto Lisp and AutoCAD. However, this system can be used for parts like stator and rotor which need only operation like blanking or piercing operations.

Various researchers have used various computer based approaches in design and manufacture of products [13–15]. From the literature review it was found designing a progressive die is problematic and complicated. Automated Knowledge based die designing systems were developed by various researchers across the globe. These automated die designing systems are not user friendly and has not given satisfactory designs. For complicated parts, simple die and compound die requires many stages of the process which is ineffective and uncomfortable resulting in a waste of time. An attempt has been made to design progressive die from Excess Hybrid or CADD application to achieve cost effectiveness and shorten the production process time [16]. This has resulted in substantial cost savings. An intelligent computer based system for selection of materials for progressive die is developed [17]. This system is capable of being changed depending upon the availability of advanced materials and new technology. The system has been tested for variety of sheet metal components and proved to be powerful and easy to handle. In the design of progressive die, an uncertainty is involved in processing the design details [18]. Fuzzy set theory is employed to assist the designer in transforming design items with fuzziness into definite and reasonable design attributes. Efforts taken to automate the design of forming punch with the objective of reducing the complexity and effort needed are described [19].

A progressive die for manufacturing gaskets is designed using SOLIDWORKS and defect analysis is carried out in production process [20]. An expert system for shearing cut progressive die, with the aim of enhancing the design of shearing cut progressive dies is designed and developed [21]. Determination of sequencing of operations in a progressive die is a challenging task [22]. A genetic algorithm to solve the problems of ranking the working steps in progressive dies is developed [23]. The developed system will enhance quality, lower cost and shorter delivery time for sheet metal products. Computer application in intelligent progressive die are discussed [24]. Very little research has been done in using machine learning to develop progressive die designing systems. This paper attempts to design the progressive die with the help of generative design technology.

III. Materials and Methods

In this study, an industrial bracket (shown in Fig. 1) is selected for manufacture by stamping process. These brackets can be used in TV antennas, projectors, street light and other commercial applications. These brackets are to be manufactured in large quantities. The component is analyzed and the various operations involved in manufacture are figured out. The bracket is to be formed in a progressive die with four operations. In the first operation, the punching of holes and notches at the desired location are to be performed. In the second operation, the center cuts to perform bending in the upcoming stage were carried out. In the third operation, blanking operation is performed to get the outline shape of the work piece. In the final operation, all the bending operations at different angles and at desired location were carried out.

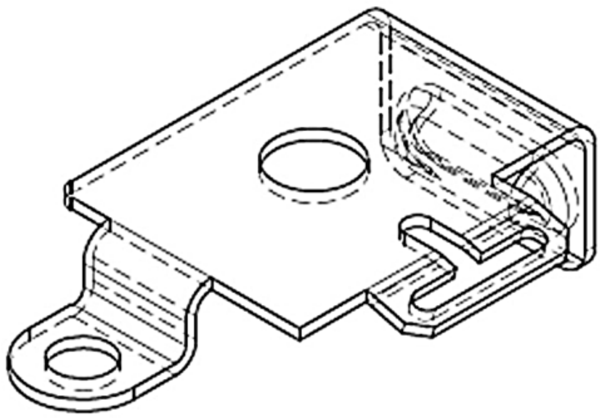

Fig. 1. Industrial bracket.

The progressive die is designed and a model of progressive die to perform the four operations is developed as shown in Fig. 3. Based on the dimensions of the bracket and the operations involved, the sizes of punches and dies were determined. The pre bending and bending forces for the various forming tools were calculated. Generative design is applied with different constraints. The studies were conducted in Fusion 360 [25].

Fusion 360 is a cloud based software platform that combines design, engineering and manufacturing techniques for different projects. This software platform has different design 3D tools sketching, direct, surface, parametric, mesh, and free-form modeling, as well as rendering, sheet metal, and assembly design. Fusion 360 makes it convenient to program CNC machines. Manufacturing features include 2D and 2.5D machining, 3-axis machining, multi-axis positional machining, 4 and 5-axis machining, turning, turn-mill, probing, part inspection, and access to advanced machining capabilities. Generative design technology in Fusion 360 enables you to explore endless manufacturing-ready design concepts and optimize for specific constraints, materials, and production processes. The software contains an in built algorithm which optimizes the design by minimizing weight. The design spacers are defined as starting shape, preserved geometry and excluded geometry. An iterative process is performed to obtain a final design outcome. The algorithm experiences numerous iterations, with the software testing the design at every iteration. The algorithm will learn to improve the design based on the constraints from the iteration, the software then applies this in the consecutive iteration, which hence becomes a better-optimized iteration. The iteration is repeated till further improvement in design is not possible. The flowchart is shown in Fig. 2.

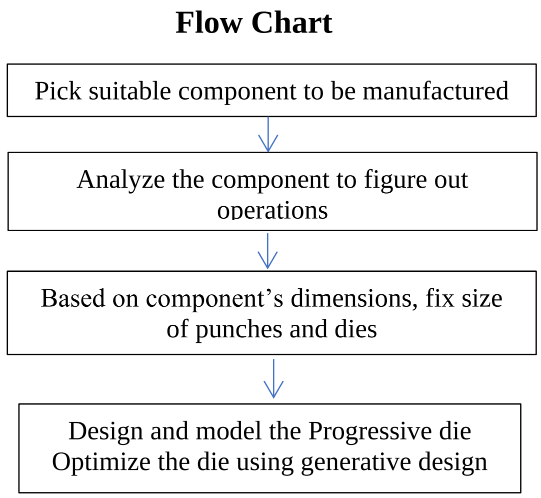

Fig. 2. Flowchart.

IV. Progressive Die Design

The types of operations to be carried out to produce industrial brackets and the materials of the various forming tools will have an impact on the design of progressive die. Moreover, the sequence of operations is a crucial factor to be considered. The designers have to develop the progressive die in such a way that the bracket can be manufactured with operations in proper sequence. In this study the progressive die is designed in four stations for the four operations. The holes and notches are formed in the first station. The die and punch are designed the operation. In the second station, the centre cut is done to conduct bending in the upcoming stage. In the third station, the outline of the work piece is blanked as per the shape of the industrial bracket. In the last station, all the bending operation is to be carried out. The model of the progressive die is shown in Fig. 3.

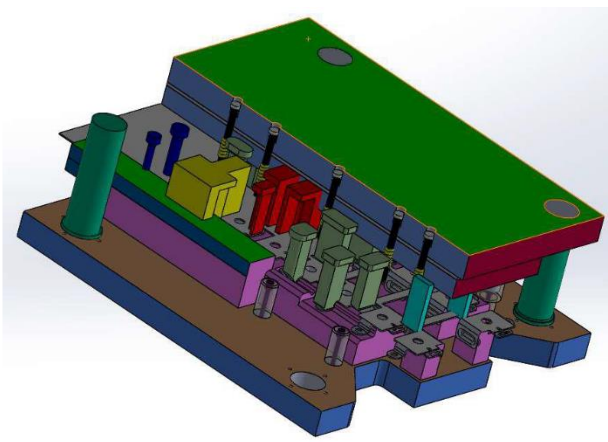

Fig. 3. Model of progressive die.

A. *Force Calculations*

Once the layout is developed, the mathematical computations are done to determine the forces for the blanking, punching, and bending operations. The bending forces are shown in the figure. The V bending force is

2,568 N while the wiping bend force is around 1,714 N. The other bending forces are shown in the Fig. 4.

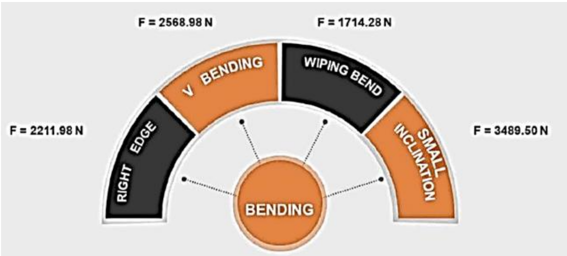

Fig. 4. Force distribution in forming tools of progressive die.

B. *Generative Design of Progressive Die*

Generative design is design technique which permits designers to give various requirements, materials and constraints to a system. The purpose is to develop designs using various algorithms as per the needs and requirements of the designers. A manufacturing ready design is generated automatically as per the requirements given by the designer. Several outcomes can be generated and a superior design can be developed without compromising the factor of safety. The entire process takes lesser time when compared with tradition form of design process. Generative design, a recent idea, expanses the limits of what's possible using other design based technologies. Software will compute all of the design options that fulfill the identified requirements.

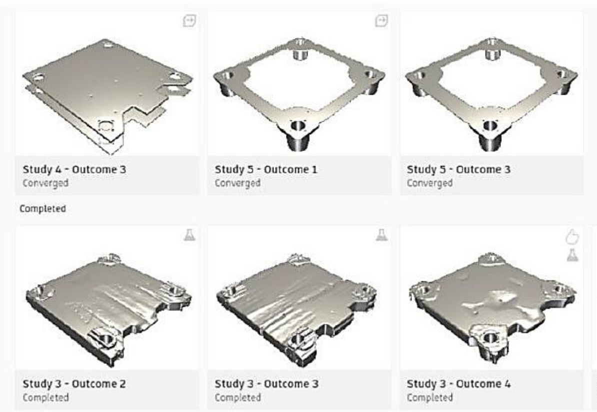

Fig. 5. Designs developed over various studies, iterations and outcomes.

Fig. 5 shows the various converged and completed designs obtained from the five studies conducted with various requirements. The outcome 1 and 3 of study 5 has given a converged solution while the outcome 2, 3, 4, 6 of the study has yielded completed designs. Several iterations were carried out in study 5 outcome 2 to minimize weight as well as to maintain factor of safety.

From Figs. 6–10, it was observed that the mass has reduced from 198.922 kg to 105.633kg during the various iterations. Further iterations have increased the factor of safety. Hence iteration 14 of outcome 2 of study 5 is considered to be the best design (Table I). The mass of the progressive die is minimized by 46.9%.This will result in the reduction of material cost of the progressive die.

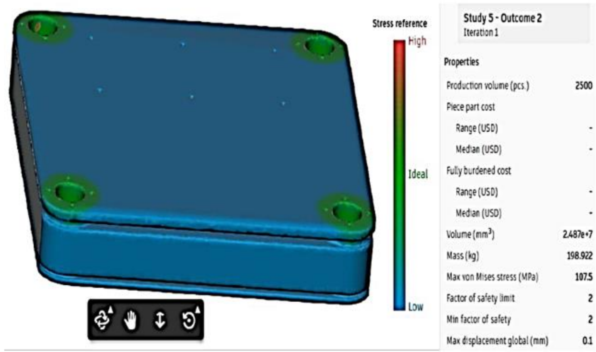

Fig. 6. Results of study 5, outcome 2, iteration 1.

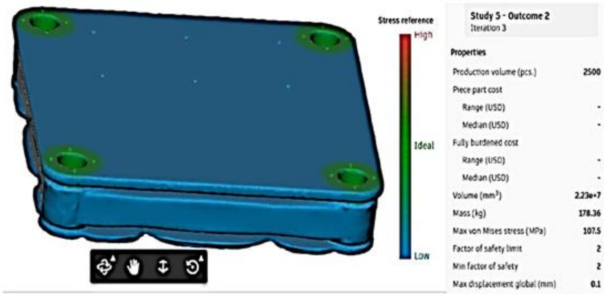

Fig. 7. Results of study 5, outcome 2, iteration 3.

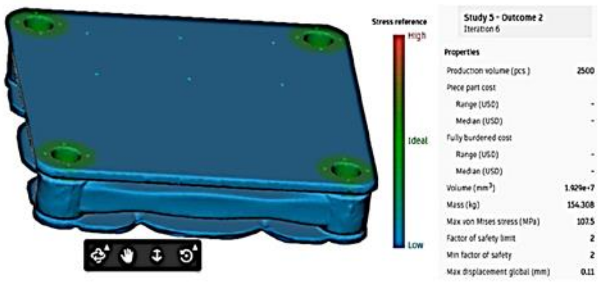

Fig. 8. Results of study 5, outcome 2, iteration 6.

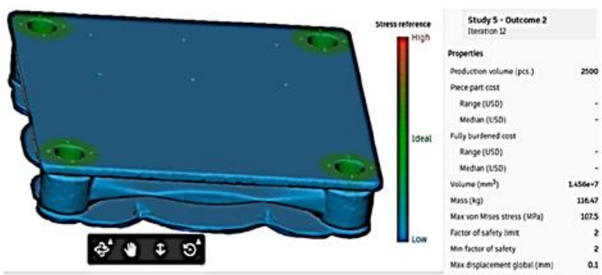

Fig. 9. Results of study 5, Outcome 2, Iteration 12.

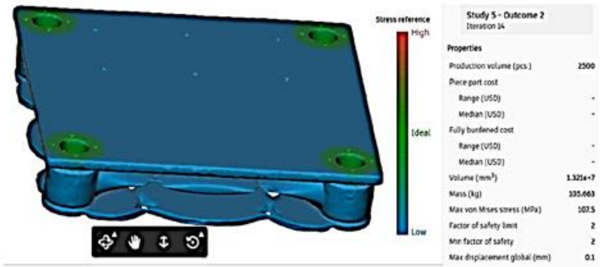

Fig. 10. Results of study 5, outcome 2, iteration 14.

TABLE I. COMPARISON OF RESULTS OF VARIOUS ITERATIONS

Study Number	Outcome Number	Iteration Number	Mass (kg)
5	2	1	198.9
5	2	3	178.3
5	2	6	154.3
5	2	12	116.4
5	2	14	105.6

V. CONCLUSION

The most optimum design of progressive die using generative design technology which is composed of an iterative Machine Learning model was presented. This project demonstrated that weight can be significantly reduced without affecting the factor of safety or any other features. Mass was reduced from almost 198kg to 105 kg by iteration without any change in factor of safety. The mass of the progressive die is minimized by 46.9%. This will result in the reduction of material cost of the progressive die. Thus, this work exhibited an effective method of reducing cost and mass of progressive die, which is very commonly used in mass production. This approach will not only reduce the cost of the tool but also the component involved. These new technologies are growing rapidly which has to be studied and implemented as soon as possible to produces more resourceful systems in the manufacturing domain.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Mahendra Kumar was involved in Conceptualization and Software. Dr Sivarajan took care of Data curation, Formal analysis, Investigation, Methodology, Project administration and Writing—original draft. V. Akash and S Akash were involved in Resources, Software, Supervision, Validation, and Visualization. All authors had approved the final version.

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