Billet Optimization for Steering Knuckle Using Taguchi Methodology

Nassir S. Al-Arifi, Abu S. Zamani, and Jalaluddin Khan

***Abstract*—In the present scenario of competitive production, Computer Aided Engineering (CAE) techniques have been applied with great success in metal forming research especially in the cold, warm and hot forging areas for meeting customer expectations. There is growing demand for more efficient and economic manufacturing process to reduce production cost, increase productivity, and reduce lead time and to improve product quality. The traditional forging die design procedure depends upon costly, tedious and time consuming shop floor trials before achieving final acceptable product. More difficulty is experienced when design requirements are stringent and die profiles are complicated. To overcome this problem, computer based simulation technology has come and brought some benefits for optimizing forging processes. In this paper, Taguchi optimization methodology is applied to optimize design parameters for steering knuckle die. Taguchi offers a simple and systematic approach to obtain optimal settings of the design parameters for steering knuckle die. The design parameters evaluated are flash thickness, flash land and billet shape each at three levels. To obtain the results the forging process was modeled (Catia 3D modeling software), simulated (Deform 3D forging simulation software) and examined using Taguchi's L_9 orthogonal array.**

***Index Terms*—Optimization; design parameters; closed die forging; simulation; taguchi method.**

I. Introduction

Manufacturing Processes face major competitions in automotive industry to produce lighter, cheaper, and more efficient components that exhibit more precise dimensions, need less machining and require less part processing. Today forging industry is facing stiffer challenges from alternative manufacturing processes. Forging industry has to be cost and quality conscious if it has to maintain its position over other manufacturing processes. With the rapid increase in affordable computing power, metal forming simulation based on finite element method is becoming a practical industrial tool[1,2,3] . By using such tool, a forge designer could decrease cost by improving achievable tolerance, increasing tool life, predicting and preventing flow defects, and predicting part properties [4].

The research involved analyzing the effect of design parameters on forging final characteristics of the product. DEFORM ™ 3D Finite Element Method (FEM) based simulation software is used to examine the effect of design parameters on forging load and die fill during forging process. The Taguchi approach enables a comprehensive understanding of the individual and combined effects of various design parameters to be obtained from minimum number experimental trials. The aim of the Taguchi design method is to establish the parameter settings which render the product quality robust to unavoidable variations in external noise [5].This paper demonstrates a technique using computational modeling and statistical-based method in optimizing the design of steering knuckle die. FEM analysis was used to predict the deformation and stress at billet of steering knuckle. Taguchi method was used to identify the importance of each design factor and suggest an optimized die design which has complete filling on normal uses and can provide appropriate flexibility [6].

II. Methodology

Taghuchi method is a powerful tool for the design of a high quality system. It provides not, an efficient, but a systematic approach to optimize designs for performance and quality.

A. Taguchi method

The Taguchi method is one of the most well-known robust design methods. The basic intention of the Taguchi approach is to develop an understanding of the individual and combined effects of various design parameters from a minimum number of experiments. The objectives of the Taguchi method for parameter design are to establish the optimal combination of design parameters and to reduce variations in the product quality by rendering the parameter design robust to the effects of noise [7]. The Taguchi method employs a generic signal-to-noise (S/N) ratio to quantify the present variation. Depending on the particular type of characteristics involved, different S/N ratios may be applicable, including "lower is better" (LB), "nominal is best" (NB), or "higher is better" (HB). The S/N ratio for the LB characteristics related to the present study is given by

$$\frac{S}{N_{LB}} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i{}^2\right)$$

where n is the number of simulation repetitions under the same design parameter conditions, yi indicates the measured results, and subscript i indicates the number of simulation design parameters arranged in the orthogonal array (OA) table. Taguchi proposed that engineering optimization of a process or product should be carried out in a three-step approach: system design, parameter design, and tolerance

Manuscript received March 3, 2011; revised July 15, 2011.

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design. In system design, the engineer applies scientific and engineering knowledge to produce a basic functional prototype design. By using the Taguchi techniques, industries are able to greatly reduce product development cycle time for both design and production, therefore reducing costs and increasing profit. The objective of the parameter design is to optimize the settings of the process parameter values for improving performance characteristics and to identify the product parameter values under the optimal process parameter values. The parameter design is the key step in the Taguchi method to achieving high quality without increasing cost. The steps included in the Taguchi parameter design are: selecting the proper orthogonal array (OA) according to the numbers of controllable factors (parameters); running experiments based on the OA; analyzing data; identifying the optimum condition; and conducting confirmation runs with the optimal levels of all the parameters. To select an appropriate orthogonal array for experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. Once the degrees of freedom required are known, the next step is to select an appropriate orthogonal array to fit the specific task. Basically, the degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. The L9 OA is shown in table 1.

TABLE I. THE BASIC TAGUCHI L9 (34) ORTHOGONAL ARRAY

Run	**Controllable factors and levels**		
	Billet size	Flash thickness	Flash land
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

If this is the case, the design parameter plays a fundamental role in determining the optimal solution of the steering knuckle die [8].

The quality of the closed die forging depends on several controlling parameters such as die design parameters and process parameters. Design parameters represent the geometrical aspect of the die such as flash thickness, flash land width, fillet radii, corner radii and draft. Process parameter is a variable related to the forging process such as process stage, load applied, shape of the die, perform and lubrication [14]. Flash is metal forced outward from the work piece while it is being forged under closed-die impression, since it is the extra metal compared to the impression cavities. Flash or excess metal extruded from the finisher impression during forging: acts as a cushion from impact blows, acts as a pressure release valve for the almost incompressible work-metal and more importantly acts as a restriction to the outward flow of the metal so that the remote corners and deeper cavities can be filled up. Another important parameter for flash gap is flash land; it is the width of the flash gap[15]. Therefore the level of both the design parameters are selected on the basis of some trial simulation and corresponding level of billet size are selected on the basis of the trail simulation.

B. Simulation

Simulation is the process of designing a mathematical or logical model of a real system, and then conducting computer-based experiments with the model to describe, explain and predict the behavior of a real system. Design by simulation is a trial and error procedure where the objective is to find a cost-effective process to manufacture a defect free product by varying process parameters [9].

Global competition requires that manufacturing industry utilizes practical and proven CAD, CAM and CAE techniques for rapid and effective process design and die manufacture. Thus numerical simulation of bulk metal forming processes is increasingly applied to eliminate forming defects, predict and optimize process variables and to predict stresses in dies for preventing premature die failure [10].

Finite element method (FEM) is a numerical approach to the problem solving. It relies on dividing a complicated problem into set of smaller and more simplified problems. Complex geometry is divided into a grid with a simplified geometry called mesh. The basic unit of mesh is called element, which is simply set of node points connected in some defined manner. Nodes stores values calculated at various time intervals of the process. The behavior of each individual element is modeled mathematically, thus the behavior of entire work piece or assembly is calculated by numerically assembling the individual elements. This approach allows doing the accurate simulation of complex forging problem. Finite element method offers the possibility of designing entire manufacturing process on a computer. This leads to reduction in cost and time for a process design [11].

III. RESULT ANALYSIS AND DISCUSSION

Selecting an appropriate perform, which meets complete die filling with the minimum force and waste material, plays a key role in the economical forging process. Because of the complicated nature of material flow in forging and its influence on the die filling of the forging parts, the ability to predict material flow, by simulation can significantly augment productivity and the skill of the designer [3]. The experience reveals that nonlinear behavior of the parameters of a forging process can only be determined if more than two levels are used. By using the conventional forging method, an experimental design was created and it employed factorial arrangements, that is, the design comprised all possible combinations of factors considering different levels. The design parameters are selected and examined each at three levels. Table 1 shows the different levels in the form of actual values for each parameter investigated.

TABLE II: THE DIFFERENT LEVEL OF ACTUAL VALUES FOR THE DESIGN PARAMETER

Parameter Destination	Deign parameters	Range	Level 1	Level 2	Level 3
A	Flash thickness (mm)	3-4	3	3.5	4
B	Flash width(mm)	16-18	16	17	18
C	Billet shape	100 RCS*120 -100RCS *110	100 RCS*1 20	100RC S*115	100RC S*110

TABLE III: TAGHUCHI'S L9

Trial no.	Billet Size	Flash thickness mm	Flash land mm	Load Ton	Complete filling
1	100 RCS*120	3	16	2698	Yes
2	100 RCS*120	3.5	17	2786	No
3	100 RCS*120	4	18	3452	No
4	100RCS*1 15	3	17	3134	No
5	100RCS*1 15	3.5	18	2575	Yes
6	100RCS*1 15	4	16	3132	no
7	100RCS*1 10	3	18	2575	yes
8	100RCS*1 10	3.5	16	2876	No
9	100RCS*1 10	4	17	2146	Yes

TABLE IV: THE INPUT DATA FOR SIMULATION TECHNIQUE USING DEFORM 3D SOFTWARE

1.Material data	
Material of Billet	AISI-1045
Billet Temperature	1100˚c
Friction factor	0.3
Thermal conductivity	35.5N/sec/˚c
Heat capacity	6.1073N/SEC^2/˚C
Emissivity	0.2
Convection coefficient	0.02N/Sec/mm/˚c
Interface heat transfer coefficient	5N/Sec/mm/˚c
2.Equipment Data (Mechanical Press)	
Capacity	2300 Ton
3.Die Data	
Die temperature	180-200˚c
Material specification	H-11
Hardness	48-49 RC

A. Developing the design matrix

The Taguchi approach enables a comprehensive understanding of the individual and combined effects of various design parameters to be obtained from a minimum number of experimental trials. The aim of the Taguchi design method is to establish the parameter settings which render the product quality robust to unavoidable variations in external noise.

In the present analysis, an L_9 orthogonal array with five columns and nine rows are used. The different levels in the form of actual values for each parameter investigated with Taghuchi's L_9 orthogonal array. The Taghuchi's L_9 orthogonal array is given in Table 2.

On the basis of above experimental set up, total 9 experiments have been conducted by the use of computer simulation technique using Deform 3D software. The input data for simulation is given in Table 3.

B. Model building and simulation control

The feasibility of using computer simulation to analyze and research the forging process of the AISI 1045 billet, by means of commercial and professional plastic forming software DEFORM-3D, the forging process of AISI 1045 billet was simulated.

The developed system can be used to generate 3D steering knuckle die geometry in STL format for FEA simulations by using DEFORM 3D software. DEFORM 3D software was adopted in this paper to get the most appropriate die geometry through the so-called computer trial-and-error method to investigate the various state variables parameters such as effective stress, effective strain, temperature and velocity. Fig. 1 shows the state variable parameters during simulation [12].

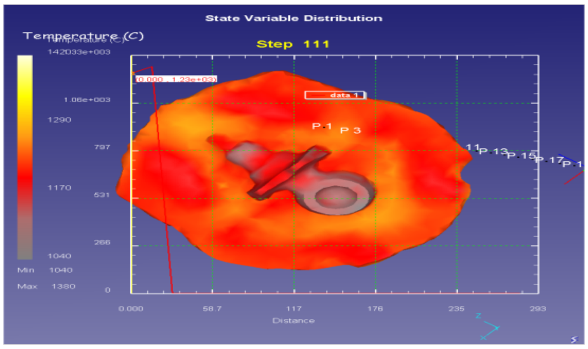

Fig. A

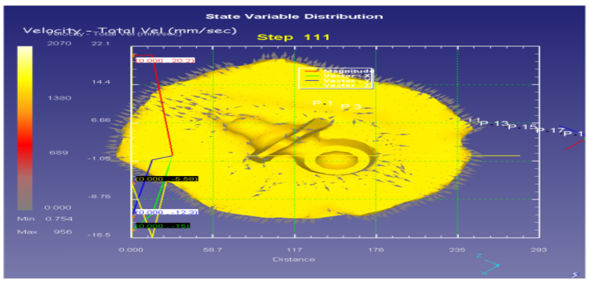

Fig. B

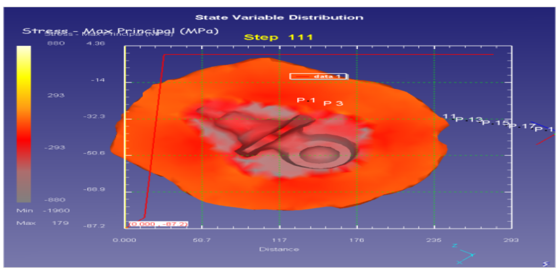

Fig. C

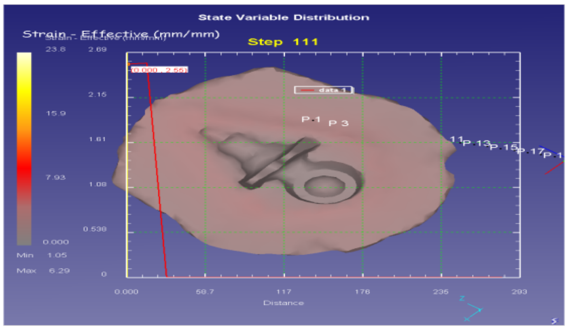

Fig. D

Fig. 1. Close look of State variables during simulation process, (A) shows the temperature distribution; (B) shows the velocity of flow of material; (C) shows the stress distribution; (D) shows effecting strain rate

This research is devoted to the implementation of Taguchi method in a forging industry and thereby, promoting an attitudinal and cultural change throughout the company. The study focuses on minimizing load and complete die fill; also forging defects like under filling and overlap are reduced by the use optimal settings of parameters. The load-time curve and volume-time curve are shown in Fig. 2.

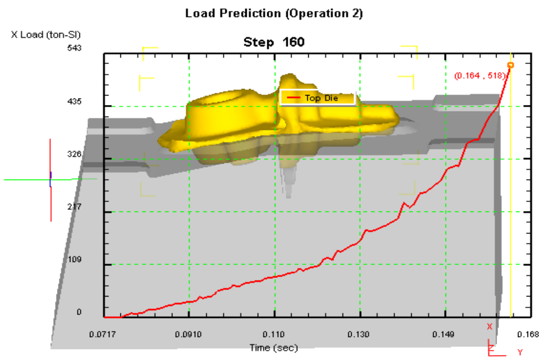

Fig. 2. load-stroke curve during simulation

IV. Signal to Noise Ratio

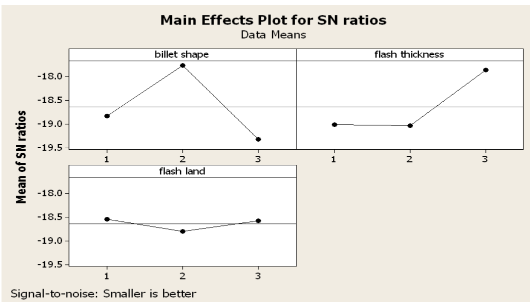

Fig. 3. Main effect plot for S/N ratios

The main effects plot of the S/N ratios for the output measures are obtained from MINITAB 15. Plots with the steeper slope along with longer lines shows that the factor has significant impact on the output parameter. The main effects plot for S/N ratios for forging yield at different levels are plotted in Fig. 3 keeping the objective as “smaller is better”.

A. *Analysis of variance (ANOVA)*

In order to study the significance of the parameters in effecting the quality characteristics of interest i.e. forging yield ANOVA was performed. ANOVA is objective decision making tool for detecting any differences in the average performance of group of items. ANOVA breaks the total variation down to accountable sources. In the present work ANOVA for S/N ratios carried out using MINITAB 15. The result obtain is shown in Table 4.

TABLE V: The result of present work ANOVA for S/N ratios carried out using MINITAB 15

S.No	Param-eters	Destination	DF	Seq	Adj	Adj MS	F	P
1	Billet shape	A	2	1.20772	1.20772	0.60386	107.68	0.025
2	Flash thickness	B	2	0.63579	0.63579	0.31789	56.69	0.071
3	Flash land	C	2	2.33783	2.33783	1.16892	208.44	0.021
	Error Total		14 26	0.07851 5.14779	0.07851	0.00561		

S=0.0748865 R-Sq = 94.47% R-Sq (adj) = 93.17%

Table 5 shows that all parameter are significant factors on forging yield because their P-values are less than 0.05. From this result, it is seen that flash land and billet size are significant factors except flash thickness. Both flash land and billet size are significant and give most contribution on the die filling.

V. Conclusions and Future Work

The following conclusions are drawn from the present investigation:

Input billet size plays very important role in forging process. Various billet sizes have been tried. It has been found that billet of sizes of 100RCS **X** 120 used in 1st trial in table 2; with flash thickness 3mm and flash land of 16mm has given complete filling. Billet size of 100RCS **X** 120 gives a load of 2361Ton and billet size 110 Ø **X** 110 gives a load of 2575Ton.

It has been found that by varying flash thickness the required forging load changes. In table 2 trial number5 with flash thickness 3.5mm and flash land 18mm gives a load of 2698Ton. Trail number 7 of the same table, with flash thickness 3 mm and flash land 18mm gives a load of 2257Ton.

Train number 9 of same table, with flash thickness 4mm and flash land 17mm gives load of 2146Ton. Thus in this trial number 9 of Taguchi L_9 orthogonal array the load is minimum with complete die filling.

The use of Taguchi technique was effective in studying the influence of these parameters on the forging yield of this crankshaft die.

An automated optimization procedure can be recommended to include parametric design tool and simulation software. The effect of flash dimension on material flow can be used as next step. This can include the interaction between perform and gutter dimensions in forging toward an optimization process leading to flash less forging process. Therewith authors try to correct other parameters design to perform by some other new methods.

One of the most important aspects of impression die forging is the proper design of performing operations and of the blocker dies, to achieve adequate metal distribution. Thus, in the finish-forging operation, defect-free metal flow and complete die filling can be achieved and metal losses into the flash can be minimized.

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