

TAGUCHI ANALYSIS OF FORGING DEFECTS FOR GEARS

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ABSTRACT

Forging is a metal forming process commonly used in industry. Forging process is strongly affected by the process temperature. In hot forging process, a wide range of materials can be used and even complex geometries can be formed. However in cold forging, only low carbon steels as ferrous material with simple geometries can be forged and high capacity forging machinery is required. Warm forging compromise the advantages and disadvantages of hot and cold forging processes. In warm forging process, a product having better tolerances can be produced compared to hot forging process and a large range of materials can be forged compared to cold forging process.

In this study, forging of a particular part which is being produced by hot forging at 1200°C for automotive industry and have been made of carbon steel, is analyzed by optimization of the forging parameter. Study has been conducted for the same temperature range in a forging company. A good agreement for the results has been observed.

Keywords: *Hot Forging, Metal Forming, Forging temperature*

1. INTRODUCTION

This chapter deals with the introduction to forging and its processes, followed by motivation of the research work and ends with research plan.

Forging and its historical aspects

The term “forging” is applied to processes in which a piece of metal is worked in a machine to the desired shape by plastic deformation of the starting stock. It is also known as a secondary manufacturing process, which converts the products from the primary operation into semi-finished or finished parts. During forging, metal is compressed under high pressure to form the desired shape products. The deformation it undergoes gives the forged parts superior mechanical properties by aligning material’s structure along the direction of deformation, eliminating the cast dendritic structure and sometimes developing a fine-grained structure as a result of recrystallization. The energy that promotes deformation is applied by a hammer, press, up setter or ring roller, either alone or in combination. The shape is imparted by the tools that contact the work piece and by careful control of the deformation process. The art of forging dates to at least 4000 BC and probably earlier. Metals

such as bronze and wrought iron were forged by early man to produce hand tools and weapons of war. Forging of wrought iron and crucible steel continued until near the end of the 19th century for similar purposes and weapons of war are still produced by the forging process using more contemporary metals. The forge-smiths of the 19th century were particularly skilled at hand or by open die forging of wrought iron. As compared to casting, forging is stronger and has a better response to heat treatments.

As compared to machining, forging has a wider size range of desired material grades and a preferable grain orientation along surface; besides, forging makes a better use of materials with the material savings as great as 75% compared to machining. Economically, forged products are attractive because of their inherent superior reliability, improved tolerance capabilities, and the higher efficiency with which forgings can be machined and further processed by automated methods. The structural reliability in forging is unexcelled by any other metalworking process. There are no internal gas pockets or voids that could cause unexpected failure under stress or impact. Often, the forging process assists in improving chemical segregation of the forging stock by moving centreline material to various locations throughout the forging.

II. CURRENT STATUS OF RESEARCH

Studies have been conducted on establishing the forging defects die wear analysis and determining the various process parameters. The surface defects were studied. The optimization technique used and the various analyses were carried out by using the FEA analysis. Most of the work is carried out in hot forging. Some work was also carried out in gear manufacturing. This chapter illustrates the review of the earlier work done on the proposed topic.

Christry Mathew, et.al.[1] The study is focused on the forging analysis of an integral axle arm produced by hot forgings are made. Forging analysis is done to explain that how the defects occur and how to prevent them. With the help of Pareto diagram, this is mostly used to identify major areas. Then the cause and effect diagram is used to explore possible causes of defects through a brainstorming session and to determine the causes which have the greatest effect. Corrective measures are being suggested to overcome the forging defects of the integral axle arms. Finally, few remedial measures and suggestions have been provided for the existing integral axle arm production process in the forging shop.

Aju Pius, Sijo.[2] The author studied and investigate the various forging defects that occur in a forging industry that causes high rejection rates in the components and remedial measures that can reduce these defects in the hot forging. The investigation was done with the help of quality assurance department within the industry. The result indicates that the rejection rate in the company was more than five percent of the total productions made each month. The defects in the forged components includes the lapping, mismatch, scales, quench cracks, under filling etc. The remedial actions includes the proper use of anti scale coating, venting process to prevent the under filling, the simulation software for determining the material flow, proper lubricant instead of furnace oil etc.

Yang and Nagil.[3] The author studied the multi-stage forging processes to ensure the production of defect-free parts. Moreover, owing to the geometry and material-flow complexities in forging processes, finding the optimal

perform shapes could be difficult and time consuming. In his paper proposes an efficient preform design methodology based on geometrical resemblance, which requires several finite element analysis simulation iterations to obtain a good perform shape. In order to verify this perform-design methodology, several case studies on forging and extrusion processes have been carried out.

Md.Israr Equbal, et.al.[4] The study focused on to improve the forging quality and decreasing the production cost. The objective of this study is to obtain an optimal perform shape in the consideration of the influence of the metal flow deformation in closed die forging process. Taguchi method has been used to simulate the closed die forging process and then performing a series of optimization iterations in order to obtain the optimal shape of the billet based on forging load minimization. The goal of the simulation and optimization process is to minimize the forging load and produce defect-free forgings. The optimal shape of the billet that gives minimum forging load with complete die filling was obtained after several optimization iterations.

Banaszek and Stefanik.[5] The author studied hot forging of anvil shape in laboratory modelling of the process of free hot forging in shaped anvils was conducted to the closure of metallurgical defects. Results obtained from the simulation and laboratory modelling were processed by using a commercial statistical package, Statistica 6.0® PL. The influence of the anvil shape and main parameters of the forging process on closure of metallurgical defects were determined. On the basis of the investigation carried out, the optimal values of the main forging technological parameters of and suitable groups of anvils to be used in particular forging stages are proposed for the elimination of metallurgical defects.

M.Poursina et.al[6] Since 1980s the problem of manufacturing defect-free parts has been tackled with simulation tools. In this paper, a numerical method for shape optimisation of pre-form dies in a two-stage hot forging is presented. The object of optimisation is to eliminate work-piece defects that may arise during the forging process. A two dimensional finite element code has been developed for the simulation of the mechanical process and prediction of the defects. The material is incompressible and it follows the Norton–Hoff law. To deal with contact constraint, the velocity-projection algorithm is used. The optimisation method is based on a genetic algorithm supported by an elitist strategy. The developed scheme is used to design optimal pre-form dies for two axi-symmetric examples. The objective function is associated with the quality of the final product. Comparing the obtained optimal results with other articles justifies the proposed optimisation method.

T.Ishikawa, N.Yukawa, Y.Yoshida and Y.Tozawa.[7] In this study, the elimination of surface micro-defects in forging is studied. The finite element analysis featuring effective meshing and an adaptive remeshing system is applied. V-shaped and rectangular scratches on the surface of billet are simulated under the axisymmetric assumption and the basic deformation of scratch during upsetting and the influence of friction on the deformation of micro-defects are discussed. During upsetting the shallow V-shaped scratch on the top surface of billet tends to disappear and deep scratch becomes lap. Defects are more likely to disappear under low friction.

F. R. Biglari, and M Zamani. [8] In this study, the wear profile on the die surface during the hot forging operation for an axisymmetric cross-section is examined. The amount of wear is calculated for two wear models by implementing a rigid thermo-viscoplastic finite element analysis into the metal forming process. The first model consists of the classical model which proposes that the amount of the wear is proportional to the die pressure and sliding length. The second model assumes that the wear is proportional to the energy dissipated on the tool/workpiece contact interface. The influence of the friction on the amount of die wear and the material flow is discussed. It was concluded that the increase of friction coefficient does not enhance the die wear in general.

M.T.Khaleed Hussain, Z.Samad, A.R.Othman, and S.C.Pilli.[9] This paper gives a review of optimization of cold forging die design and dies design process, which has been done by many authors using different techniques. The fatigue behavior and fatigue failure of the die when it under go cyclic loading is studied. The study concluded with future challenges of the die design and its processes, the approaches adopted to develop an optimum system that can fulfill the customer demand.

Sung-Woo Bae and Yohng-Jo Kim.[10] In this study the design of die shapes for the forging process of a hollow flange, computer simulations were carried out using the rigid-plastic finite element method. Forging defects like folding were seen in the vicinity of die corners at the typical shape ratios of upper and lower dies. Die shape ratios at which the forging defect could occur during the extrusion-forging process of the hollow flange were investigated.

M. Mirsaedi, F.R.Biglari, K.Nikbin and E.Moazami Goudarzi.[11] In the present study, a new method for forging preform design has been developed based on linear interpolation technique. The use of preform shapes obtained by this technique would result in enhancement of the geometrical and mechanical quality of final part. Among the obtained preform shapes the one preform that gives more uniform accumulated equivalent plastic strain. Using plasticine as an ideal material to validate the findings it is shown that by the use of this optimum preform shape, the geometrical defects such as under filling and fold over defects may be eliminated in the final product.

III. EXPERIMENTATION

Process optimization and Taguchi method

Statistical methods are commonly used to improve the quality of a product or process. Such methods enable the user to define and study the effect of every single condition possible in an experiment where numerous factors are involved. Defect analysis is such a process in which a number of control factors collectively determine the performance output i.e. the defect percentage. Hence, in the present work a statistical technique called Taguchi

method is used to optimize the process parameters leading to minimum defect during forging process of gear and axle shaft under study.

Table 1.1: Parameter settings for defect analysis.

Control factor	Symbols
Weight of billet	Factor A
Temperature	Factor B
Forging time	Factor C
Initial die temperature	Factor D

Taguchi experimental design

Taguchi technique is a powerful tool for design of high quality systems based on orthogonal array experiments that provide much-reduced variance for the experiments with an optimum setting of process control parameters. It introduces an integrated approach that is simple and efficient to find the best range of designs for quality, performance and computational cost. From a scientific viewpoint, these experiments are either one or a series of tests to either confirm a hypothesis or to understand a process in further detail. Experiments from a manufacturing point of view, however, are concerned with finding the optimum product and process, which is both cost effective and of a high quality. In order to achieve a meaningful end result, several experiments are usually carried out. The experimenter needs to know the factors involved, the range of these factors are varied between, the levels assigned to each factor as well as a method to calculate and quantify the response of each factor. This one factor at a time approach will provide the most favorable level for each factor but not the optimum combination of all the interacting factors involved. Thus, experimentation in this scenario can be considered as an iterative process. Although it will provide a result, such methods are not time or cost effective. But the design of experiments is a scientific approach to effectively plan and perform experiments, using statistics. In such designs, the combination of each factor at every level is studied to determine the combination that would yield the best result. The advantage of such design schemes is that it will always determine the effect of factors and possible interactions (between factors) on the result.

Taguchi design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The most important stage in the design of experiment lies in the selection of the control factors. Therefore, initially a large number of factors are included so that non-significant variables can be identified at earliest opportunity. In the present work, the impact of five such parameters are studied using L_9

(3¹³) orthogonal design. The operating conditions under which defect analysis is carried out for gear and axle shaft are given in Table 1.2.

Table 1.2: Levels for various control factors for gear.

Control factor	Level			Units
	I	II	III	
A: Weight of billet	2.1	2.2	2.3	Kg
B: Temperature	1180	1200	1220	°C
C: Forging time	11	13	15	sec.
D: Initial die temperature	200	225	250	°C

IV. TAGUCHI ANALYSIS OF DEFECTS FOR GEAR AND RESULTS

Table 1.3: Experimental design (L₉ orthogonal array) with output and S/N ratio for forging defects in gear.

S. No.	Weight of billet (A) (kg)	Temperature (B) (°C)	Forging time (C) (sec.)	Initial die temperature (D) (°C)	Defect (%)	S/N Ratio (db)
1.	2.1	1180	11	200	4	-12.0412
2.	2.1	1200	13	225	6	-15.5630
3.	2.1	1220	15	250	4	-12.0412
4.	2.2	1180	13	250	7	-16.9020
5.	2.2	1200	15	200	5	-13.9794
6.	2.2	1220	11	225	7	-16.9020
7.	2.3	1180	15	225	4	-12.0412
8.	2.3	1200	11	250	6	-15.5630
9.	2.3	1220	13	200	5	-13.9794

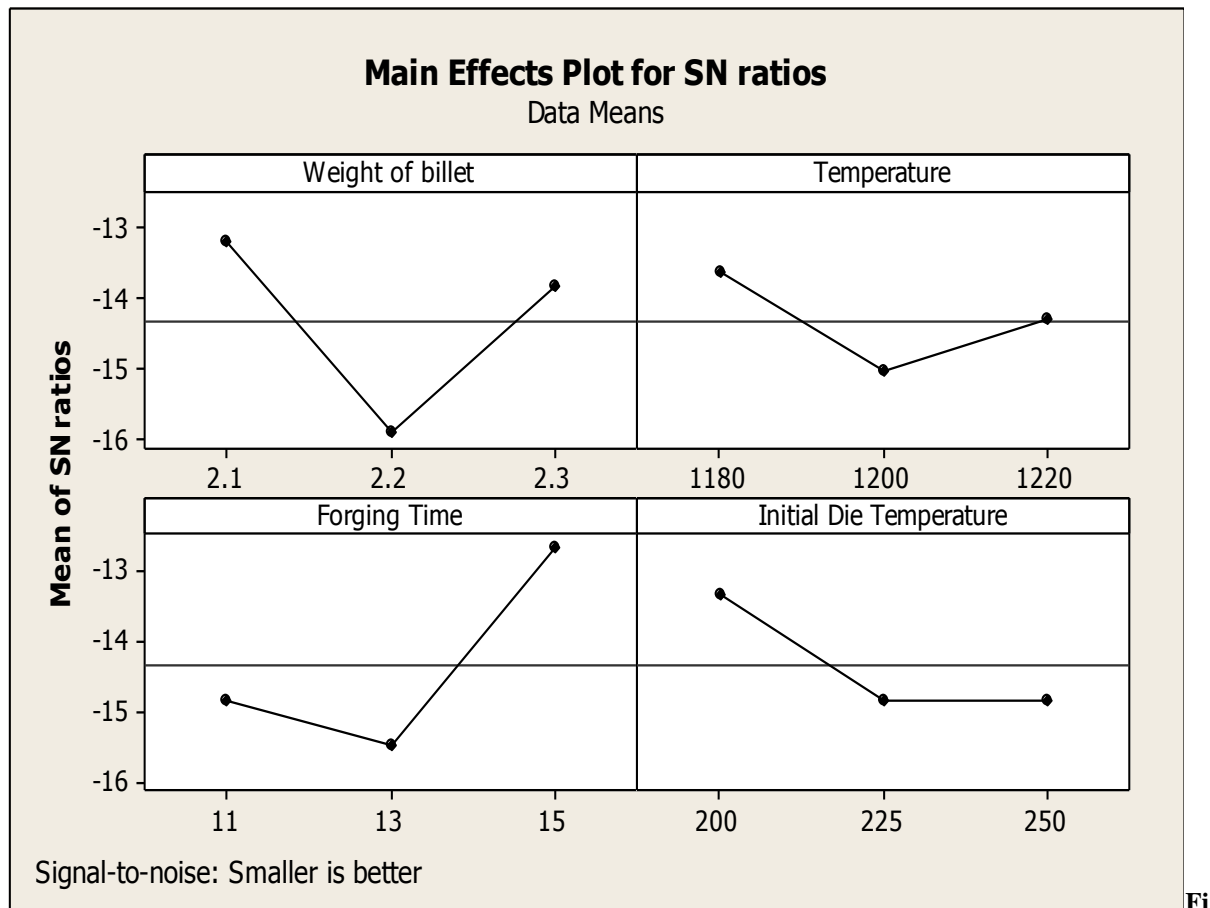


Figure 1.1: Effect of control factors on defects during forging of gear.

Table 1.4: Response table for signal to noise ratios.

Level	Weight of billet (A)	Temperature (B)	Forging time (C)	Initial die temperature (D)
I	-13.22	-13.66	-14.84	-13.33
II	-15.93	-15.04	-15.48	-14.84
III	-13.86	-14.31	-12.69	-14.84
Delta	2.71	1.37	2.79	1.50
Rank	2	4	1	3

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