REVIEW OF TAGUCHI METHOD, DESIGN OF EXPERIMENT (DOE) & ANALYSIS OF VARIANCE (ANOVA) FOR QUALITY IMPROVEMENTS THROUGH OPTIMIZATION IN FOUNDRY

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Abstract: In the foundry defects like blow holes and sand drop in castings lead to rejection of castings and affect productivity. Taguchi Method, founded by Dr. Taguchi, significantly improves quality and engineering productivity can be used in various casting process also by taking into the attention of various Noise factors. Taguchi Method is a statistical approach to optimize the process parameters and improve the quality of various parts that are manufactured in the foundry. Design of experiments (DOE) can be used in the foundry as a systematic method to regulate the relationship between factors disturbing a various casting process
The purpose of this review paper is to give details analysis of Taguchi method, Design of Experiment method for optimization in the foundry for the various casting process. This paper discusses efforts of various researchers attempted to optimize the various casting process parameters by conducting the analysis of variance (ANOVA) experiments to minimize the defects in the casting process in the foundry and for improving quality and productivity.This paper also explain various benefits and critical success factor achived.

Keywords: - Taguchi method, Design of Experiments (DOE), ANOVA, Foundry

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I INTRODUCTION

Dr. Genichi Taguchi and Electrical Communication Laboratories (ECL) in Japan with help of Research &Development try for improving the productivity and enhancing product quality. Taguchi approaches are statistical methods established and developed by Dr.Genichi Taguchi to improve the quality of manufactured products and in past few years it can also apply to engineering product (Rosa et al. 2009) ,biotechnology (Rao et al. 2008, Rao et al. 2004), marketing and advertising (Selden 1997) and can apply to another area also. Good Taguchi method assists the professional statisticians to receive the goals and for obtaining improvements, particularly by Taguchi's development of designs of experiments for studying variation in a process. After World War II, the Japanese manufacturers were tense to continue with very limited resources in their organization. The main challenge of any mass production is variability and inconstancy in production and products. The success in reducing variations. It will always simplify the manufacturing processes; reduce scrap and defects and lower costs of production. (Box and Bisgaard 1988). The main intention in the Taguchi method is to design robust systems that are more reliable and consistent under uncontrollable conditions with an overall goal to improve quality of a product. (Taguchi 1978, Byrne1987 and Phadke1989).The method aims to adjust the various design parameters of the process.

In this method, main importance and thrust was given to the process of creative brainstorming and thinking to reduce the expenditure and cost of resources utilized for production. It was found that that poor quality of any product cannot be improved by the various inspection methods, acceptance sampling method, screening, and salvaging. Various expense and volume of inspection cannot put quality back into the product. So Taguchi thought that quality concepts should be based upon, and developed around, the thinking of prevention of poor quality product rather than control it afterward by inspections on the main principle of prevention is better than cure to minimize defects and improve quality.

Dr.Taguchi motivated to develop new methods to optimize the process of engineering experimentation called Design of experimentation (DOE). Dr. Taguchi thought and developed the finest way to improvement in quality was to design and shape it into the product. He established the methods which are now known as Taguchi Methods. His main involvement is not only in the mathematical formulation of the design of experiments, but it includes in its connected thinking. His thoughts produced an exclusive and fundamental quality improvement technique that changes from traditional methods He recognized manufacturing or production systems that were "robust" or insensitive to daily and seasonal variations of surroundings, like machine or tool wear and other external factors for variation His techniques arise entirely out of following ideas.

The concepts are:

1. Quality should be designed into the product stage earlier and not in inspection after manufacturing of the product so here think of quality concept before manufacturing of a product.
2. Quality can better obtain by reducing the deviation from a target means desired specification and reducing rejections. The product should design according to for good quality by protecting it from uncontrollable environmental and other disturbing factors.
3. The quality cost should be measured as a function of deviation from the standard and the losses should be measured in system-

Taguchi proposed a standard 8-step procedure for applying his method for optimizing any process in a process can be applied for sand casting process in the foundry also.

8-Steps in Taguchi Methodology:

Step-1: Determine the main function of any process, side effects, and failure mode.
Step-2: Discover various Noise Factors, prevailing testing Conditions, and Quality Characteristics.

Sep-3: In the third stage categorize the objective function to be optimized in the production process.
Step-4: Classify the control factors and their levels.
Step-5: Select the appropriate orthogonal array matrix for the various experiments.
Step-6: Conduct the various experiments.
Step-7: Investigate the data obtained; predict the optimum levels and performance.
Step-8: Complete the verification experiment and plan the future action.

II TAGUCHI DESIGN OF EXPERIMENT (DOE)

DOE method can be classified by two ways full factorial design and fractional factorial design**,** a full fractional design can be used to identify all the likely combinations for a known set of various factors. In all industrial experiments usually demand a significant number of factors, a full factorial design effects in performing a large number of experiments, this method is very costly and time-consuming method [k Farkas et al 2007]. So that this fractional factorial design is recommended by choosing a limited number of experiments from all the possibilities that make the most information in order to reduce the number of experiments to a practical level. The fractional factorial design is popular to solve the problem, this design is complex and there are no common guidelines for its application or the analysis of the results obtained by carrying out the experiments [R. S. Rao, et al 2008).

R. A. Fisher introduced Design of Experiments (DOE) as a powerful statistical procedure in England in the 1920's to study the effect of multiple variables concurrently. In his initial applications, Fisher completed agricultural experiments to find out how much rain, water, fertilizer, sunshine, etc. Factors are required to harvest the best crop from land. Since that time, much development of the technique has been done in the academic situation by various researchers; it also helps to generate many applications in the production shop and shop floor for the various processes. Dr. Taguchi finished significant research with DOE techniques in the late 1940's as a researcher in Electronic Control Laboratory (Japan). Dr. Taguchi put extensive effort to make this experimental technique easier and simplify to improve the quality of products manufactured in any industry. Dr. Taguchi's regular version of DOE, generally known as the Taguchi technique or Taguchi approach, was introduced in the USA in the starting of1980's. Nowadays it is one of the most effective quality constructing tools used by engineers in all types of manufacturing processes like casting in the foundry.

The DOE using Taguchi methodology can carefully satisfy the needs of problem-solving and
Product/process design optimization projects. Due to a knowledge of this method and effective application of this technique, engineers, scientists, and researchers can considerably reduce the time necessary for experimental investigations in any production process.
DOE can be highly effective by two ways
(1) In first way optimization of product and process designs in the first step then, study the effects of multiple factors (i.e. - variables, parameters, ingredients, etc.) on the process or performance, and solve production problems by objectively setting out the investigative experiments to fulfill overall application goals.
(2)In a second-way study effect of individual factors on the performance and deciding that which factor has more effect on the process and which factor have less effect. Anyone can also find out which feature should have the tighter tolerance and which tolerance should be relaxed in process. The facts and figures from the experiment will decide how to allocate quality assurance resources based on the objective data. It will show whether a supplier's part causes problems or not with help of ANOVA data, and it also indicates how to pool different factors in their appropriate situations to get the best results with precise objectives.
DOE using the Taguchi approach has become nowadays a much more attractive and popular instrument to practicing engineers and scientists for optimization. The Design of Experiments is considered as one of the most inclusive approaches in product/process development. It is a statistical approach that challenges to provide a predictive knowledge of a complex, multi-variable process with few trials (K S Anastasiou et al.)

III. TAGUCHI ORTHOGONAL ARRAY (OA):-

To solve the complexity of handling a large number of experiments, which usually comes into the picture in case of experimental design procedures such as simple factorial design or central composite design with the increasing number of process variables, Taguchi (1990) has developed certain standard orthogonal arrays by which the simultaneous and independent evaluation of two or more parameters could be performed in the entire space (Nilrudra Mandal et al)

It is designed is a type of general fractional factorial design. It is a highly fractional orthogonal design that is built on a design matrix suggested by Dr. Genichi Taguchi, This method permits you to consider a selected subset of combinations of multiple factors at multiple levels. Taguchi Orthogonal arrays are well-adjusted to confirm that all levels of all factors are considered similarly. For this reason, the factors can be assessed unconventionally even though the fractionally of the design.

IV ANALYSIS OF VARIANCE (ANOVA)

Taguchi method is applied to for invention of optimal process parameters analysis of variance (ANOVA) is a combination of statistical models used to investigate the differences between group means and their associated procedures developed by statistician and evolutionary biologist Ronald Fisher.

ANOVA is technique that can apply for evaluation the percentage contribution of various process parameters on the selected performance characteristics. This ANOVA provides the information about how important is the effect of each controlled parameter on the quality characteristics of attention. The total variation in the result is the sum of variation due to various controlled factors, their interactions and due to experimental error. It can be said that ANOVA for raw data and S/N data can be applied to find the significant parameters and measures or calculate their effect on the performance characteristics in process.

V TAGUCHI METHOD, DESIGN OF EXPERIMENT AND ANOVA IN FOUNDRY FOR THE CASTING PROCESS.

The manufacturing processes mean casting in foundry set-up are multivariate in nature. Casting process in the foundry is also known as a process of ambiguity. In completely controlled casting process also have defects in casting products which contests explanation about the source of casting defects. The complexity and difficulty of the process are due to the involvement of the various areas of science and engineering with casting. The cause of defects is not due to a single factor but it depends on the combination of several factors. So that DOE (Taguchi Method) is used for analysis sand and other mold-related defects such as sand drops, sand fusion, extra material etc.

Casting process, it involves a large number of parameters affecting the various casting quality features of the product. Green sand casting provides adequate green strength to get dimensional stability and to provide an excellent surface finish in the product. There is a number of various experimental investigations linking green sand casting parameters with casting quality have been carried out by researchers and the foundry engineers over the past few years [park 1990]. It has been recognized and accepted that the design of green sand casting parameters impacts casting quality. The casting process includes a large number of parameters that may affect the quality of castings. Some of these parameters which affect the quality are controllable, while others are uncontrollable. (A. Kumaravadivela et al 2012).

For casting process in the foundry to perform research or innovation in the foundry environments, generally, there is no as such criteria exist and experimentation at different values of input variables have been performed in hit and trail manner (McLeod, 2000). In observation of a large number of factors which are accountable for casting defects in various steps of the process, the general statistical methods and approach are not always given better results. (Dulluri and Raghavan, 2009). An alternate and well-designed pattern recognition methodology are found to be suitable and correct for the metal casting-foundry related problems.

Taguchi method of design of experiments is used to optimize the process parameters in the casting process of the foundry. Results can be analyzed using ANOVA technique to know the percentage of contribution of each casting process parameters. Various researchers try to optimize the sand casting process parameters by conducting the analysis of variance (ANOVA) experiments on Taguchi's concept to minimize the defects in the casting process. The Taguchi method with multiple performance characteristics can be used in the foundry for obtaining a set of an optimal system in casting process and parameters based on the defined objectives.

The basic steps for achieving the above target are summarized below {Enright TP et al (1983) & Roy RK (1990)}

1. To select the important parameters that cause of variations in the quality characteristics of any product or process.
2. In the foundry casting defects have been selected as the most typical quality characteristics in the green sand or any other casting process, because it is connected to many internal defects like sand blow holes, pinholes, scabs, metal penetration, mold shift, mold crack, sand drop, cracks or another. The target of the green sand casting or any other process is to achieve "lower casting defects" while minimizing the effect of uncontrollable parameters or factors.
3. Make casting process under the experimental conditions given by the chosen orthogonal array and parameter levels. Depending upomBased on the experimental conditions, collect the data.
4. In an analysis of variance (ANOVA) table is created to decide the statistical significance and meaning of the parameters. Response graphs are plotted to define the preferred level for each parameter.
5. After that optimum situation of the control parameters and prediction of the results of each of the parameters at their new optimum levels is done.
6. Verification of the optimum settings is done with result anticipated like the decrease in the casting defects in the foundry.

VI RESEARCH METHODOLOGY

In this paper total 16 different case study of casting The Foundry Company for critical examination DESIGN of experiment (doe) & analysis of variance (ANOVA) for quality improvements through optimization in the foundry. All the case studies which are selected in this paper are from established publications to show the real research The main aim of this study is to find out the benefits which Taguchi methods with design of experiments and ANOVA in the foundry for quality improvement, For this Two different table are prepared for critical analysis Table 1 shows Overview of Research papers with publications. Authors name case study. (Table-1) .Table -2 show various parameter taken for optimization, tools/ methods used, a method used for deciding significate parameters, No of experiments and Level Benefits/Result Achieved and Critical success factor achieved.

Table-1 General Overview of Case Industries (Foundries) with use of Taguchi method, Design of Experiment (DOE) & ANOVA.(With their reference no in fourth column)

Sr no Case study paper	Title of Paper	Author	Journal Name Publication	Case Study and Type of Process
T-1	Optimization of Sand Casting Process Parameter Using Taguchi Method in Foundry	Rasik Upadhye & Dr. Ishwar P Keswani (Refrence-35)	International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 7, September – 2012.(	The purpose of this paper is to optimize the sand casting process parameters of the castings manufactured in the iron foundry by maximizing the signal to noise ratios and minimizing the noise factors using Taguchi method.
T-2	Taguchi Optimization of Process Parameters on the Hardness and Impact Energy of Aluminum Alloy Sand Castings.	John O. OJI, Pamtoks H. SUNDAY, Omolayo M. PETINRIN, Adelana R. ADETUNJI (Refrence-11)	Leonardo Journal of Sciences Issue 23, July-December 2013 p. 1-12	An optimization procedure for sand casting process parameters based on the Taguchi method is described in this paper. While keeping other casting parameters constant, for aluminum alloy castings.
T-3	Optimization of Sand Casting	Kidu Geberecherkos	International Journal of Engineering Trends and Technology (IJETT) – Volume-	This research is planned to optimize the sand casting Process(Akaki Basic Metal Industry)parameters of trash plate castings

	Process Parameters for 46MnSi4 Alloy Steel Trash Plate Castings Applicable for Roller Stand.	Weldeanenia Asmamaw Tegegne Abebe (Reference-16)	41 Number-8 – November 2016	manufactured from 46MnSi4 alloy steel in ferrous metal foundry applicable for roller stand of sugar industry.
T-4	Determining the optimum green sand casting process parameters using Taguchi's method.	A. Kumaravadivel U. Natarajan and C. Ilamparithia (Reference-17)	Journal of the Chinese Institute of Industrial Engineers.Vol. 29, No. 2, March 2012, 148–162	This study determines optimization of sand casting process parameters using Taguchi's design of experiments method An attempt has been made to obtain optimal level of the process parameters in order to generate the optimum quality characteristics of the cast iron flywheel castings.
T-5	Reduction Of Casting Defects Using Taguchi Method.	Arun Basil Jacob, Arunkumar O.N (Refrence-3)	IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) (ICETEM-2016) 278-1684,p	This paper aims at the reduction of casting defects of a plate cylinder which is used in an offset printing machine to transfer ink from the inking unit. Four variables are considered which directly affect the casting of the cylinder.
T-6	Application of Taguchi's methods to investigate some factors affecting microporosity formation in A360 aluminum alloy casting	O¨mer Savas Ramazan Kayikci (Reference-23)	Materials and Design 28 (2007) 2224–2228www.elsevier.com/locate/matdes	In this paper a Taguchi design investigation has been made into the relationship between the microporosity and process variables in a sand cast A360 aluminum alloy.
T-7	Elimination Of Porosity In Steel Casting: An Experimental Approach	K. N. Anand and A. K. Chaudhuri (Reference-15)	Quality Engineering, 10(1), 9-16 (1997-98)	An alloy steel foundry with a monthly capacity of 20 tones of casting was facing a chronic problem of porosity in one particular type of casting.
T-8	Optimization of the aluminum die casting process based on the Taguchi method	K S Anastasiou (Reference-12-	Proc Instn Mech Engrs Vol 216 Part B: J. B: J Engineering Manufacture IMechE 2002	Greek aluminum die casting company for die casting process to improve casting quality.
T-9	Minimization of the Casting Defects Using Taguchi's Method	Harvir Singh, Aman Kumar (Refrence-10)	International Journal of Engineering Science Invention Volume 5 Issue 12|December 2016 PP. 06-10	This case study is carried out to reduce casting defects at AV VALVE Pvt Ltd, Agra.
T-10	Numerical optimization of gating system parameters for a magnesium alloy casting	Zhizhong Suna, Henry Hua, Xiang Chenb (Refrence-44)	Journal of materials processing technology 1 9 9 (2 0 0 8) 256–264	An optimization technique for design of gating system parameters of a cylindrical magnesium casting based on the Taguchi method with multiple performance characteristics is proposed in this paper

	with multiple performances characteristics			
T-11	Using sol-gel component as additive to foundry coatings to improve casting quality	U. Nwaogu, T. Poulsen, B. Gravesen and N. Tiedje (Refrence-42)	International Journal of Cast Metals Research 2012 VOL 25 NO 3	This paper investigates the effect of using the sol-gel component as an additive to the foundry coatings applied on chemically bonded sand cores.
T-12	Optimization of Casting Process Parameters using Taguchi Method	Ganesh G. Patil, Dr. K. H. Inamdar (Refrence-9)	International Journal of Engineering Development and Research(IJEDR)2014 | Volume 2, Issue 2	This paper, green sand casting process was optimized by using Taguchi method.
T-13	Process Factor Optimization to Enhance Productivity of Green Sand Casting Process by Using Taguchi Methodology	Rajesh Rajkolhe, J. G. Khan (Refrence-27)	International Journal of Research in Advent Technology, Vol.2, No.6, June 2014	This paper discusses application of Taguchi method in Green sand casting process.
.T-14	Determination of optimum sand mix for CO_2 core	K. N. Anand (Refrence-14)	Total Quality Management, VOL. 9, NO. 7, 1998, 563 ± 572	An exploratory study using statistical The experimental design was conducted considering 8 variables to determine the optimum sand mix composition for manufacturing CO_2 core.
T-15	Parametric optimization and Solidification analysis of gray cast pump adapter castings using DOE and CAE – a case study.	Rathish Raghupathy & K.S. Amirthagadeswaran (Refrence-27)	Australian Journal of Mechanical Engineering Australian Journal of Mechanical Engineering	In this work, gray cast pump adapter casting process in a foundry is optimized to produce quality at M/S Best Engineers Pumps Private Limited, Coimbatore and Indo Shell Cast Private Limited.
T-16	Investigation of ductile iron casting process parameters using Taguchi approach and response surface methodology	A. Johnson Santhosh and A. R. Lakshmanan (Refrence-1)	Overseas Foundry, China Foundry Vol.13 No. 5 September 2016	This Case Study Is Carried Out to find the optimized levels of various casting parameters in the ductile iron casting, various casting defects, and the rejection rate were observed from a medium scale foundry.

Table-2 showing SR.No, Various Analysis, and Description for each case study shown in Table-1

Sr No of paper case study	Various Analysis for Critical Examination	Description for each paper/case study for column-2
T-1	*No of Factors and parameters for Case study*	Total Eight Sand particle size Moisture percentage in sand Green compression strength Mould hardness Permeability Pouring temperature of molten metal Pouring time of molten metal in mold Pressure test
	Tools/Methods used	S/N Ratios Analysis of Variance (Anova)
	No of experiments and Level	The standard Taguchi L9 Orthogonal Array (OA) format is chosen
	Benefits/Result Achieved	The improvement expected in minimizing the variation is 37.66 percent which means reduction of casting defects from present 6.16 percent to 3.84 percent of the total castings produced in the foundry
	Critical success factor achieved	A robust method for formulating a strategy to find optimum factors of process and interactions with a small number of experiments
T-2	*No of Factors and parameters are taken FOR case study*	No of factors (parameters) 5 Mould Temperature (°C)Pouring Temperature (°C) Runner Size (mm^2) Hardness (HRB) Impact Energy (Joule)
	Tools/Methods used	ANOVA Analysis of the S/N Ratio
	No of experiments and Level	The standard Taguchi L9 Orthogonal Array (OA) format is chosen from preliminary works
	Benefits/Result Achieved	Analysis of the results shows that 100°C mold temperature and 700°C pouring temperatures are optimal values for hardness and impact energy. But, 200 mm^2 and 285 mm^2 runner sizes are the optimal values for hardness and impact energy individually.
	Critical success factor achieved	An optimization technique for sand casting process parameters based on the Taguchi method is reported in this paper. While keeping other casting parameters constant, aluminum.
T-3	*No of Factors and parameters(variables) Taken for case study*	Three factors (Pouring temp.(^OC) Runner size (cm^2) Pouring time(sec))
	Method used for deciding significate parameters	Physical observation, brainwashing, and interviews of 15 workers including, casters, mold makers, pattern makers, expertise and managerial groups to gather expert were used in conducting the research. Dimensions of the actual trash plate patterns were designed using CATIA V5 software considering machining allowance, shrinkage allowance and draft angel that was given by the foundry experts of the case industry.
	Tools/Methods used	Taguchi DOE method, Minitab, and ANOVA, CATIA V5 software
	No of experiments and Level	The experiment was initially designed using Taguchi L9 Orthogonal array approach total level Three-(low medium and high)
	Benefits/Result Achieved	Optimum settings of the selected process parameters namely pouring time, runner size and pouring temperature ware 82 seconds, 62cm^2 and 1672 ^{0}Crespectively. The contribution of factors was analyzed using ANOVA method and results obtained are pouring time accounted equals 66.33% of the total effect, the runner size 19.44% and pouring temperature was 6.27%.
	Critical success factor achieved	Applied methods for determination of the casting defects and the optimum settings of factors were achieved successfully.
T-4	*No of Factors/ parameters(variables) Taken for case study*	Total 9 parameters (Moisture content, Permeability, Loss on ignition strength. Volatile content. Vent holes. Pouring time. Pouring temperature. Mold pressure
	Method used for deciding significate parameters	A cause-and-effect matrix is drawn to identify the casting process para The KPIVs are listed on the left-hand side, While the key process output variables (KPOVs) are listed on the top right-hand side of the diagram meters with respect to key process input variables (KPIVs).
	Tools/Methods used	ANOVA, DOE S/N Ratio Taguchi method
	No of experiments and Level	The total degree of freedom (DOF) for nine factors, each in three levels and two second-order interaction, is Hence, a three-level OA, with at least 26 DOF, has to be selected. The L27 OA having 26 DOF is selected for this study.
	Benefits/Result Achieved	In this study higher product yield can be obtained because, prior to the application of the Taguchi method, the casting defects of the casting process were 7.703%, and after the application of Taguchi's method, the casting defects of the casting

		process declines to 7.32% in this study. It shows the reduction in the average percentage of rejection rate of sand casting process by 0.38% and process sigma level of the company has increased to 3.68 from 3.47.
	Critical success factor achieved	Improves the productivity of the castings Produced Taguchi's method has yielded optimized control factors, resulting in superior product quality and stability.
T-5	*No of Factors/ parameters(variables) Taken for case study*	4 parameters Moisture content (%),Green Strength(g/cm^2), Sand Particle size(AFS), Mould hardness (nu)
	Method used for deciding significate parameters	From detailed study, the four factors which can control almost all the defects were found
	Tools/Methods used	Orthogonal array, Taguchi, ANOVA, MINITAB software
	No of experiments and Level	design matrix for the L9 array for four factors and three level
	Benefits/Result Achieved	The percentage rejection of the plate cylinders can be reduced to 3.40 % which is a significant improvement in this case
	Critical success factor achieved	Taguchi method is thus a cost-effective method which can be used in industry to reduce the wastage of cast parts with the existing industry resources
T-6	*No of Factors/ parameters(variables) Taken for case study*	Five factors Modification, Hydrogen level, Solidification Time, Filtering, Filling condition.
	Method used for deciding significate parameters	More practical significance of microporosity and from past experience for a reliable design to produce high-quality aluminum cast parts above factor are taken
	Tools/Methods used	Design of experiments, Analysis of variance (ANOVA)
	No of experiments and Level	8 experiments and two level
	Benefits/Result Achieved	Dissolved hydrogen level of the liquid alloy has important effect on the extent of microporosity, but Results showed that the microporosity is overwhelmingly due to the dissolved hydrogen (i.e. no traces of shrinkage porosity was observed) and ranging between 0.04% and 1.72% within the castings
	Critical success factor achieved	Taguchi method can be used to investigate the five well-known factors, which have been proposed to affect the microporosity formation, in a sand cast A360 aluminum alloy in a foundry.
T-7	*No of Factors/ parameters(variables) Taken for case study*	Total 15 Factors: - Fresh charge, Carbon in metal %, Chromium in metal Superheating time (min) furnace temperature ("C), Directions of molding, Pseudofunctor nested in Machining allowance (mm), Chill, Core venting. Core painting Choke area in gating system, Deoxidizer, Pouring rate/Grain size of molding. Sand (AFS No.)
	Method used for deciding significate parameters	Factors and their levels of the alloy steel casting porosity The experiment was identified in a brainstorming session with the technical people concerned, including the chief executive of the plant.
	Tools/Methods used	Analysis of variance (ANOVA, Design of Experiment, Orthogonal array
	No of experiments and Level	Total 32 Experiments,2 level
	Benefits/Result Achieved	The porosity was reduced to less than lo%, as compared to 59-70% earlier. The company has saved about Rs 0.10 million per annum.
	Critical success factor achieved	An orthogonal array (OA) design developed by Taguchi was used to find a solution to this chronic problem. in steel casting porosity experiment
T-8	*No of Factors/ parameters(variables) Taken for case study*	Total 5 parameters Holding furnace temperature (in degree C). Die temperature (Degree C), Piston velocity, ®rst stage (m/s), Piston velocity, second stage (m/s), Hydraulic pressure (bar)
	Method used for deciding significate parameters	An Ishikawa diagram (cause and effect diagram,) is constructed to identify the casting process parameters that may affect the die casting porosity
	Tools/Methods used	L27 Orthogonal Array process parameters, S/N ratios, Taguchi method
	No of experiments and Level	Three-level Orthogonal array with 27 experimental runs was selected.
	Benefits/Result Achieved	The predicted mean estimation of casting porosity was calculated as 0.07119 percent with a confidence interval of between 0.06422 and 0.07817 percent
	Critical success factor achieved	Considerable reduction in porosity formation can be obtained by Taguchi technique implementation in the die casting process
T-9	*No of Factors/ parameters(variables) Taken for case study*	Four parameters: - 1. Pouring Temperature (^{o}C) 2. Sand Particle Size (AFS) 3.Mould Hardness Number 4. Permeability Number.
	Method used for deciding	A model is also created for optimization of castings process through simulation

	significate parameters	and the major causes are predicted and its solutions are given by defect diagnostic approach.
	Tools/Methods used	MINITAB-17 statistical software, Taguchi Method
	No of experiments and Level	L9 Orthogonal Array
	Benefits/Result Achieved	These optimum solutions were applied on casting process and the calculated the percentage rejection 4.416 of the products. Thus we could improve 1.25% in casting defects.
	Critical success factor achieved	For minimizing the casting defects using Taguchi's method through the change in various parameters like as pouring temperature, green strength, mold hardness and permeability.
T-10	*No of Factors/ parameters(variables) Taken for case study*	Three parameters Product yield (%) Shrinkage porosity (%) Filling velocity (cm/s)
	Method used for deciding significate parameters	Cylindrical housing model was used as the test sand casting to demonstrate the numerical optimization
	Tools/Methods used	Magmasoft, analysis of variance (ANOVA) signal-to-noise (S/N) ratio,
	No of experiments and Level	Experimental plan using L9 orthogonal array
	Benefits/Result Achieved	The product yield has decreased by 1.57%, the shrinkage porosity is decreased by56.57% and the filling velocity is decreased by 58.05.
	Critical success factor achieved	The Taguchi method with multiple performance characteristics has been demonstrated for obtaining a set of optimal gating system parameters based on the defined objectives
T-11	*No of Factors/ parameters(variables) Taken for case study*	Three (3) parameters Sol-gel component S, Viscosity V. Dipping time D
	Method used for deciding significate parameters	Discussion and Brainstorming
	Tools/Methods used	Taguchi method, Analysis of variance (ANOVA), MAGMAsoft version 5 software, Design of Experiment (DOE)
	No of experiments and Level	L9 33 OA for three parameters at three levels (Total 9 Experiments)
	Benefits/Result Achieved	All the parameters (sol-gel component, viscosity and dipping time) contributed to the reduction of the surface roughness of the castings.
	Critical success factor achieved	Taguchi experimental design was adopted and applied in this investigation to elucidate the effects of three parameters at three levels on the target performance Response (surface roughness).
T-12	*No of Factors/ parameters(variables) Taken for case study*	Mould hardness, Moisture Content (%), Permeability No, Green Compression Strength (gm/cm^2) are the main parameters.
	Method used for deciding significate parameters	An Ishikawa diagram (cause and effect diagram) is created to identify the casting process parameters that may influence green sand casting defects.
	Tools/Methods used	Taguchi method, DOE, analysis of variance (ANOVA
	No of experiments and Level	Taguchi based L18 orthogonal array (18 Experiments)Total -3 level
	Benefits/Result Achieved	Optimized process parameters of the green sand castings process which leads to minimum casting rejection. The optimized parameter levels are mold hardness number–90, moisture content–4.75%, green strength–1400 gm/cm2, and permeability number–135.
	Critical success factor achieved	The experiments give a clear picture of every factor's contribution to the variation in the green sand casting process, and the quality can be improved without additional investment.
T-13	*No of Factors/ parameters(variables) Taken for case study*	Four(4) Parameters, Sand particle size(AFS), Mould hardness(NU), Green compressive Strength(gm/cm^2), Permeability(NU)
	Method used for deciding significate parameters	Selection of the most significant parameters that affect quality characteristics is done by analysis.
	Tools/Methods used	Taguchi Method, ANOVA, Design of Experiment(DOE),
	No of experiments and Level	Standard Orthogonal Array's L9 is used.
	Benefits/Result Achieved	With Taguchi optimization method the % acceptance of castings has increased from 91.66% to 94.5, in this study.
	Critical success factor	Improvement in quality of green sand castings through process control, keeping

	achieved	the effects of uncontrolled parameters at a minimum level
T-14	*No of Factors/ parameters(variables) Taken for case study*	11 Total factors Sand (AFS no.), Sodium silicate (%),Collapsible agent, Silicon (%),Dextrine (%),Coal dust (%),Dexil (%),Moisture (%),CO^2 gas passing time (s), Shelf-life, Temperature.
	Method used for deciding significate parameters	The factors and levels were analyzed in a brainstorming session with the faculty from the foundry division of the Indian Institute of Science, Bangalore, and the foundry technical personnel.
	Tools/Methods used	orthogonal array (OA) layout (Taguchi method), analysis of variance (ANOVA).
	No of experiments and Level	The experiment was designed with an L 32 (231) orthogonal array (OA) layout involving 32 experiments.
	Benefits/Result Achieved	Core breakage at the green stage is totally eliminated, The experimentation has been quite economical because the results were achieved by carrying out 32 trials only.
	Critical success factor achieved	A fractional experiment using the OA layout developed by Taguchi has helped in identifying the critical core sand mix parameters and their best levels for improving the strength at the green stage and achieving high collapsibility at the knockout stage.
T-15	*No of Factors/ parameters(variables) Taken for case study*	Total Three parameters: - Clay (%), Moisture (%), Mould hardness (kg/cm^2) three different levels are taken in this case study.
	Method used for deciding significate parameters	Process parameters that are found to be significant have the reasonable effect on the quality of pump adapter castings from observation and discussion.
	Tools/Methods used	DOE and CAE PROCAST simulation
	No of experiments and Level	Total 15 Experiments,
	Benefits/Result Achieved	The pump adapters produced during the confirmatory trials revealed no defects and hence rejection rate in the pump adapter castings is highly reduced with DOE and CAE tools.
	Critical success factor achieved	The results of DOE, as well as CAE, have been recommended for implementation in industry that can produce shrinkage porosity-free castings.
T-16	*No of Factors/ parameters(variables) Taken for case study*	Total 7Parameters:- Pouring temperature (°C), Inoculation (wt. %), Carbon equivalent (%), Moisture content (%), Green compression strength ($gm \cdot cm^2$), Permeability, Mould hardness are various parameters.
	Method used for deciding significate parameters	The settings of the process parameters are determined by discussion using Taguchi's experimental design method.
	Tools/Methods used	"MINITAB 17". Software, Taguchi method, (ANOVA), S/N ratios
	No of experiments and Level	L-27 orthogonal array with 3-level settings so total 27 experiments
	Benefits/Result Achieved	The experiment results showed that with the optimized parameters, the rejection rate was reduced from 16.98% to 6.07%.
	Critical success factor achieved	An increase in inoculation results in a significant improvement in acceptance percentage of ductile iron castings.

VII LESSON LEARNED / OUTCOMES OF THIS STUDY

After optimization of various factor level with Taguchi method results in the reduction of casting defects and increase the yield percentage of the accepted castings without any extra investments or extra cost. With the use quality tools like Pareto chart the major defects in the daily operations of foundry can find out and quality of castings can be improved by aesthetic, visual look, dimensional accuracy, better understanding of noise factors gathered the interaction between variables, quality cost system based on individual product, scrap reduction, reworking of castings and process control. (Rasik A Upadhye et.al. 2012**)**

In one case study of alloy steel casting, it is observed that the casting was influenced by casting defects such as sand sintering, solidification shrinkage cavity, porosity, surface roughness, run and slag and other defects. Detail investigation finds that casting problems happened in castings are due to the incorrect input process parameters such as pouring temperature, gating system design in casting, pouring speed and time and others that involved in the overall casting process of the castings. For that, in the first analysis, part interview and brainstorming can be done with the help of the foundry experts, advisors and workers employed in the foundry shop to evaluate the critical casting defects occurred during the sand casting process. Sometimes uncertain moisture content in the old sand is the possible causes for porosity formation during the casting process. The reclaimed sand proportion is the main reason for sand sintering defects. Low controlling mechanisms of melting and solidification temperatures to gather with unskilled labor while making a mold and pouring of the molten metal are other various reasons for casting defects. In general lack of close control of the process and non-optimized parameter, utilizations are considered as main factors for defect formation in sand casting in the foundry.(Kidu Geberecherkos 2016).

Taguchi's methodology can be used for optimizing process parameters of casting in the foundry. The Design of Experiments (DOE) cab carried out in following steps: • Selecting appropriate output variables or responses like rejection in casting. • Selecting appropriate factors or parameters (input variables) like moisture, mold temperature etc in sand casting. • Setting appropriate factor ranges or levels as per requirements and normally used.. • Creating appropriate documentation for the experiment. • Handling the experiment as it is carried out. • Reporting and presenting results using software or any other method (ANOVA). DOE can be selected based on the various casting parameters with appropriate levels and orthogonal array can apply (A. Johnson Santhosh et al. 2016).

Mold filling with the pouring of molten metal in a mold cavity and solidification processes of the various casting are simulated with the various simulation software. The simulation results specified that gating system parameters considerably touch the quality of the casting. To obtain the optimal process parameters of gating system, an orthogonal array, the signal to noise (S/N) ratio, and analysis of variance (ANOVA) can be used to investigate the effect of various gating system designs on cavity filling and casting quality using a weighting method. (Zhizhong Suna et al 2008).

Taguchi design with various experiments for different factors and levels and with help of various techniques like Analysis of variance (ANOVA) can be performed on S/N (signal-to-noise) ratios to decide the statistical significance and contribution of each factor on the surface roughness of the casting. Taguchi design can be used to investigate experimentally the effect of volume of casting, pouring temperature of different materials and shell mold wall thickness on the surface roughness of the castings obtained by using ZCast direct metal casting process. (Munish Chhabra et al 2012).

8 CONCLUSION

Following conclusion can be drawn from above review study**.**

- Taguchi method is originated on performing assessment or experiments to test the compassion of a set of response variables to a set of control parameters (or independent variables) by in view of experiments in "orthogonal array" with an aim to get the optimum set of the control parameters and it can be applied in casting process in the, foundry.
- In the various research paper, casting defects are studied to find out the factors causing it. The reduction of defects was done by optimizing the control variables or factors affecting the output. Taguchi method is the best accessible method to optimize the factors and together with the help of analysis of variance the optimum control factors are also found out.
- The casting process is very random and difficult to control before the application of Taguchi's technique due to large members of parameters of the casting process, the product quality adversely affects due to variability problems. Taguchi's method has yielded improved control factors, ensuring better product quality and constancy in casting process in the foundry for better quality.
- Due to the application of Taguchi method higher product yield is obtained in casting process also because, prior to the application of the Taguchi method, the casting defects of the casting process is found higher in the different case study. The reduction in average percentage of rejection rate of sand casting process by application of Taguchi method and quality improvement is done.
- In the various study, it can be seen that fractional factorial experiments using the orthogonal array layout accepted by Taguchi have assisted in identifying as many critical material and process parameters in the casting process and their best levels for eliminating the porosity and other defects in an alloy steel casting.
- Taguchi method and the factor levels when optimized will result in the reduction of casting defects in the foundry and rise the yield percentage of the accepted castings without any extra investments. A use of quality tools like Pareto chart is beneficial for finding the major defects in the daily operations of the foundry. Quality of castings can be improved with reducing defect or rejection rate.
- Design of Experiments (DOE) is a commanding statistical technique for determining the optimal factor setting of a process and thereby obtaining improved process performance can be used in casting process in all the foundry also. It can be used for improving quality and reducing a cost of production.
- Taguchi method has been used for more than half century for the optimization of parameters of various production processes; but, an examination of the various case study has discovered that there are, effective industrial applications of Taguchi-based optimization approaches in determining the optimal settings of process variables for casting process in a foundry. Because of its practicality and robust designing and optimizing the experiment.
- Taguchi's experimental design to casting process in foundry process improves the productivity of the various castings products produced and increase the stability of the casting process. Taguchi's experimental design yielded optimized control parameter resulting in higher product quality and stability. The range of process parameters are also desired.

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