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IMPROVEMENT OF PAINTING PROCESS IN STEEL STRUCTURE USING TAGUCHI'S METHOD OF EXPERIMENTAL DESIGN

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Abstract: **The present competitive market is focusing industrial efforts on producing high-quality products with the lowest possible cost. To help accomplish this objective, various quality improvement philosophies have been put forward in recent years and of these, TAGUCHI (DOE) is most viable and efficient technique for process quality improvement. This project illustrates the analysis of the various parameters in painting process by experimental design. For the analysis the painting process in steel structure is examined. In fabrication, the painting process constitutes the greatest portion of affecting quality, reprocessing process and impact on process cost. For Every industry to have their profit margin intact with their competitive edge in the market, production should be in such way that rejection and reprocessing should be minimum.**

The prime focus is to minimize the excess consumption of paint in steel structures. And also improve the paint coverage, coating thickness to reduce the rework, touch-up painting process. With repetition and confirmation experiments the parameter are determined and optimum level of these parameters are defined, for improvements of quality.

Keywords: **Design of Experiments, Pareto Analysis, ANOVA, Optimization of Paint Consumption, Steel Structures.**

I. INTRODUCTION

Experiments are performed today in many manufacturing organizations to increase our understanding and knowledge of various manufacturing processes. Experiments in manufacturing companies are often conducted in a series of trials or tests which produce quantifiable outcomes. For continuous improvement in product/process quality, it is fundamental to understand the process behaviour, the amount of variability and its impact on processes. METCO Roof Private Limited, established in the year 2002, with the commitment for offering world class products in Pre-Engineered Building Systems (PEB) complete in Design, Development, Manufacture and Erection, tuned to national and international quality standards with consistency and customer satisfaction.The steel fabrication company, offering the complete range of fabrication services from estimates and engineering to fabrication and installation. By integrating all these activities under one roof, we are better able to control the production process and the quality of our steel structures.

The type and amount of paint used for a particular project is always dependant on the particular conditions of the project and the client's specifications. We work with our clients to decide what is right for their needs, based on the corrosive atmosphere at the project location (wet/dry climate, proximity to salt water) and the number of years the property owner would like the building to be protected. In this work, we want to investigate the influence of excess paint consumption in steel structure. Use Design of experiment that allows collecting data at combinations of factors involving in painting process, and then use the findings to adjust manufacturing conditions. Because resources are limited, it is very important to get the most information from each experiment to perform. The optimal composition of parameters is to minimize the amount of paint consumption and maximize the paint coverage is evaluated.

II. METHODOLOGY

A. Problem definition

There are several problems are occur in that company. We concentrate on below process.

- Excess paint, but less coverage
-
- Rejection and rework in paint
- Improper coating

While doing painting, usually certain parameters like paint coverage area, coating thickness, and painting cost will not be kept in our mind, due to delivery schedule of the product.

If we take all the parameters in our mind, no doubt, we will be able to save excess usage and also improve the efficiency.

B. Data Collection

The below stages are involving in the painting process. We want to collect the data from each category.

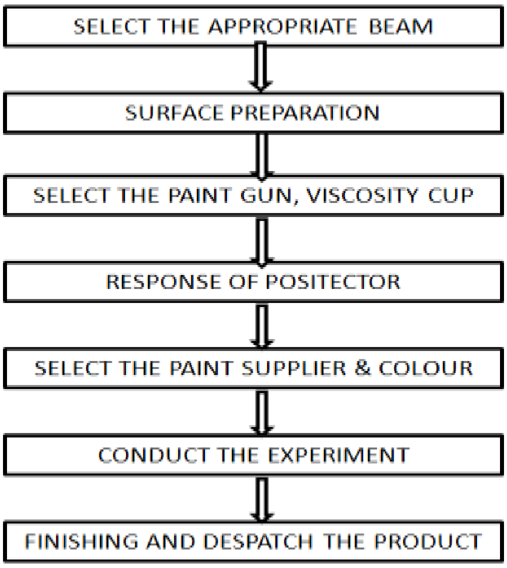

Fig.1 Painting Process

For surface preparation, we ensure that the spraying area is clean, dry, and free from dust, oil, grease or any other contaminant. A dirty or greasy surface will affect adhesion, and spoil the finish and is very difficult to correct once sprayed.

The response of paint gun shown in Fig.2, the proper needle, nozzle and air cap combination is critical to the optimal performance of any spraying system. Size of the needles and nozzles should be selected based on the viscosity of the coating being applied and the finish and application speed required. For non-viscous materials (thin viscosity), select a smaller size needle and nozzle. For viscous materials (thick viscosity), select a larger size needle and nozzle. For better results, use the needle and nozzle that performs best with the trigger of the gun fully engaged.

Fig. 2 Paint Gun

To select the desired spray pattern, rotate the air cap at the front of the gun. When the air cap is in the diagonal position, the spray pattern will be round; when in the horizontal position, the spray pattern will be vertical; and when in the vertical position, the spray pattern will be horizontal.

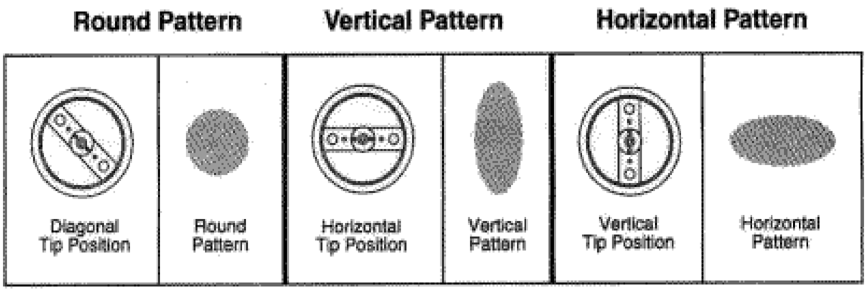

Fig. 3 Spray Pattern

Viscosity plays a major role in painting process. The thickness of a coating is defined by its “viscosity in seconds”: “Viscous coatings” are thicker materials; “non- viscous coatings” are thinner materials. To properly measure the viscosity of a coating, viscosity cup is used.

Metco has several paint suppliers, but for procuring bulk order Metco consider only few reputed suppliers, based on the quality, delivery and cost criteria. After comparing cost and other parameters, we have selected SURFA COATS as our prime supplier.

C. Problem Analysis

To analyze the input variables or factors that might affect the painting performance and quality, the process is observed thoroughly.

Cause & Effect Diagram for identifying the possible Influential parameters in this process. There are several inputs in this paint process that could potentially affect its performance. Cause-and-effect diagram (Ishikawa Fishbone) to help to determine which factors will provide the most beneficial outcome in paint usage. We can identify the possible Influential parameters, with the help of expert paint operators and maintenance technicians, & floor level engineers etc,

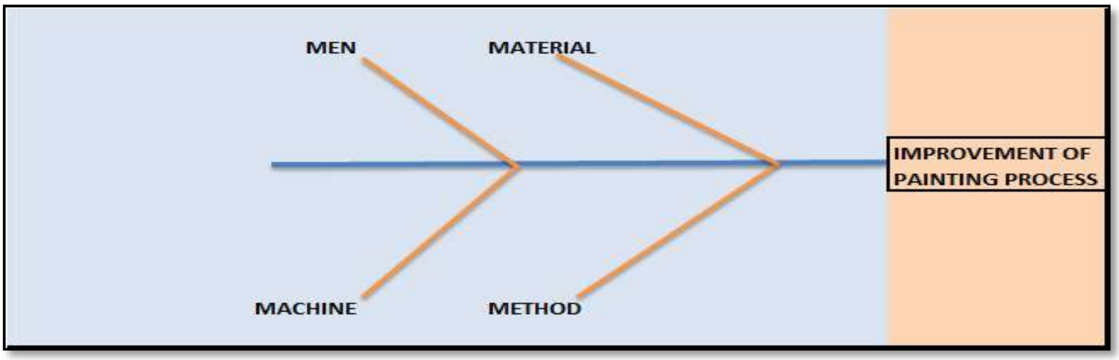

Fig.4 Cause and Effect Diagram

For each category such as (men, method, machine and materials) possible factors are mentioned in Table I

TABLE-I IDENTIFICATION OF FACTORS

MEN	METHOD	MACHINE	MATERIAL
MISALIGNMENT	IMPROPER MIXING	AIR COMPRESSOR	PAINT TYPE
IMPROPER FINISHING	DRYING TIME	GUN TYPE	PAINT BRAND
IMPROPER PLACEMENT	PERFORM TO HOLD THE EQP	NOZZLE/NEEDLE	PAINT COLOUR
IMPROPRE HANDLING		PRESSURE	
LACK OF KNOWLEDGE			

Pareto principle, is sometimes referred to as the 80/20 rule. In quality, this rule suggests that 20% of defect categories will account for 80% of the total number of defects. The user details and number of factors collected and illustrated in a Pareto Chart (see Fig.5)

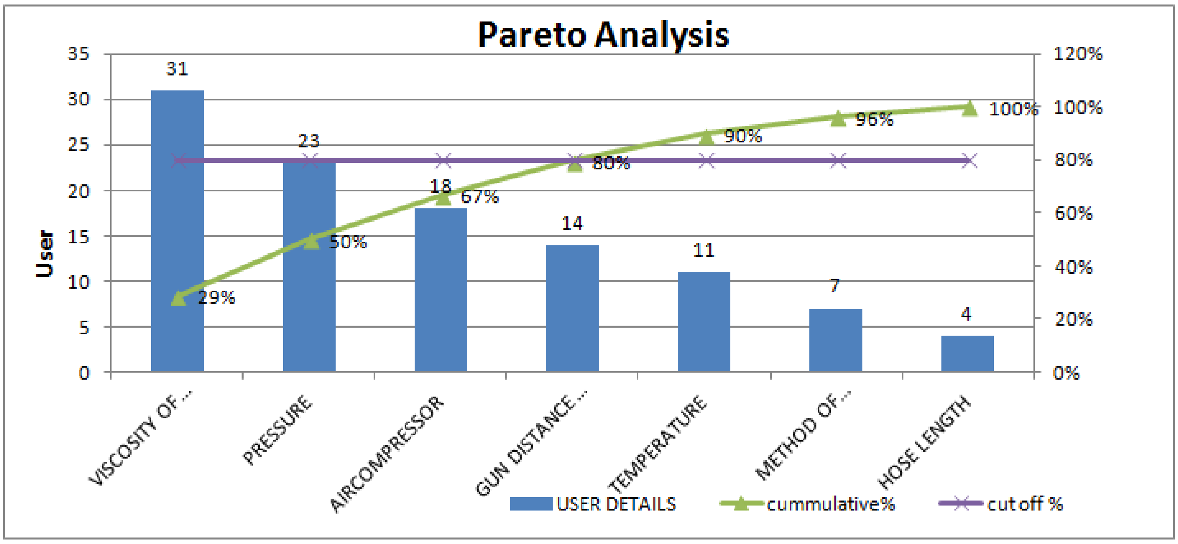

Fig.5 Pareto Analysis

Use QC tools such as Cause and effect, Brainstorming and Pareto. The overall process consists of four main factors: Viscosity of paint, pressure, air compressor and gun distance.

D. Experimental Design and Implementation

Experimental Design with two replications is used to carry out the test in two methods.

- Data Analysis Using Taguchi Experiments
- Data Analysis Using ANOVA

Data Analysis Using Taguchi Experiments:

The DOE using Taguchi approach can economically satisfy the needs of problem solving and product/process design optimization projects. By learning and applying this technique, engineers, scientists, and researchers can significantly reduce the time required for experimental investigations.

Taguchi OA experiment first we determine the degree of freedom and levels of factors. All factors are to be studied at two levels. Hence, choose a two level OA. The required degree of Freedom is 7. (see Table II). To summarize, the four factors and the test levels are presented in Table III.

TABLE II REQUIRED DEGREE OF FREEDOM

FACTOR	LEVEL	DOF	DF
A	2	(2-1)	1
B	2	(2-1)	1
C	2	(2-1)	1
D	2	(2-1)	1
AB		(2-1)(2-1)	1
AD		(2-1)(2-1)	1
BD		(2-1)(2-1)	1
TOTAL			7

TABLE III LEVELS OF FACTORS

FACTORS	UNIT OF MEASUREME	OPERATING RANGES	PROPOSED LEVELS	
			LEVEL 1	LEVEL 2
VISCOSITY OF PAINT	SEC	90-100	90	100
PRESSURE	KGF/SQ M	2.8 TO 4.2	2.8	4.2
AIR COMPRESSOR	HP	1 TO 3	1	3
GUN DISTANCE FROM WORK PIECE	INCH(MM)	10 (254 MM)	7	10

The OA which satisfies the required Degrees of Freedom is L_8 OA
Main factors = 4
Interactions possible in L_8 =3.

Therefore, the best orthogonal Array would be L_8

Based on the experiment superimposed the required linear graph on the standard linear graph (see Fig.6).

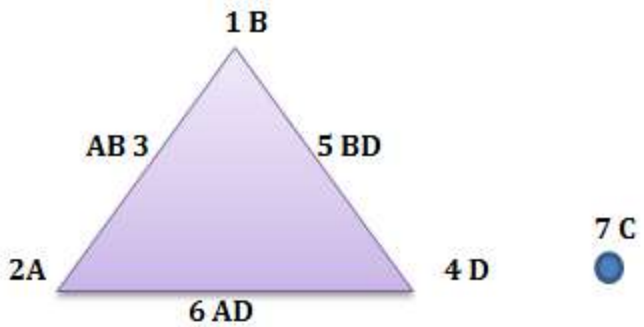

Fig. 6 superimposed linear graph for illustration table II

According to Fig 7, for painting process, we have to determine the best level of process parameters in order to maximize the paint coverage area. The sample PEB FRAME is given below.

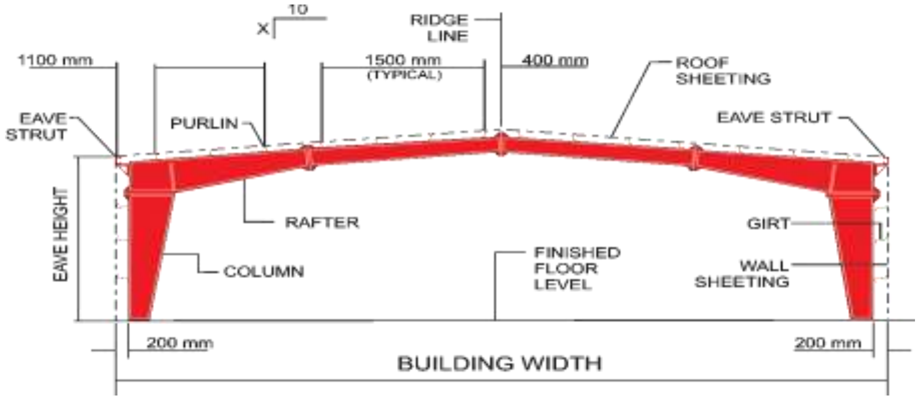

Fig. 7 Painted Frame

For conducting the experiment, we prepared the test sheet without the interaction columns. During experimentation, the levels are set only to the main factors and also interaction column can be omitted in the test. However, interaction columns are required for data analysis. For run the experiment, we take sample paint for one ltr and response is mentioned below.(see Table IV)

TABLE IV ASSIGNMENT OF FACTORS AND INTERACTION

TRAIL NO	FACTORS							Replication		
	B	A	AB	D	BD	AD	C	R1	R2	Total
	1	2	3	4	5	6	7			
1	1	1	1	1	1	1	1	4.25	3.25	7.5
2	1	1	1	2	2	2	2	7.05	6.75	13.8
3	1	2	2	1	1	2	2	7.05	6.45	13.5
4	1	2	2	2	2	1	1	4.85	3.98	8.83
5	2	1	2	1	2	1	2	6.89	7.1	13.99
6	2	1	2	2	1	2	1	4.42	4.68	9.1
7	2	2	1	1	2	2	1	4.51	4.45	8.96
8	2	2	1	2	1	1	2	6.98	7.2	14.18
										89.86

According to Table V, the response totals are converted into average response and the absolute difference in the average response of the two levels of each factor is also recorded. This difference represents the effects of the factor. These differences are ranked starting with highest difference as rank 1, the next highest difference as rank 2 and so on.

TABLE V AVERAGE RESPONSE AND RANKING OF FACTOR EFFECTS

Response total for each factor							
FACTORS	**B**	**A**	**AB**	**D**	**BD**	**AD**	**C**
LEVEL 1	43.63	44.39	44.44	43.95	44.28	44.5	34.39
LEVEL 2	46.23	45.47	45.42	45.91	45.58	45.36	55.47
Avg response and ranking of factor effects							
LEVEL 1	5.45	5.55	5.56	5.49	5.54	5.56	4.30
LEVEL 2	5.78	5.68	5.68	5.74	5.70	5.67	6.93
DIFFERENCE	**0.33**	**0.14**	**0.12**	**0.25**	**0.16**	**0.11**	**2.64**
RANK	2	5	6	3	4	7	1

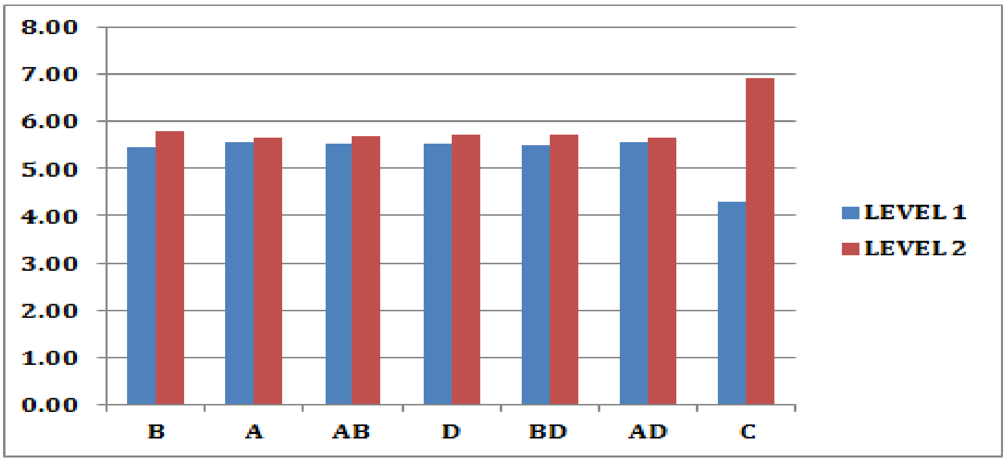

Fig. 8 Average Response Graph for illustration table 5

According to Fig 8, factor C should be set at high level. The objective is maximization of the response, so the optimum condition is selected based on the higher mean value 5.6 of each factor. From the response graph the optimum condition is given below.

TABLE VI OPTIMUM LEVEL

FACTORS	UNIT OF MEASUREMENT	OPTIMUM LEVEL	LEVEL 2(RANGE)
A (Viscosity)	SEC	2	100
B(pressure)	KGF/SQ M	2	4.2
C(Air Compressor)	HP	2	3
D(Gun Distance)	INCH	2	10

E. Experimental Verification

Before using the optimal combination as a working standard, another set of experiments is performed to verify the replicable of the experiment.

Data Analysis Using Analysis of Variance This method accounts the variation from all sources including error term. For statistically validating the result, ANOVA is required. The ANOVA table for the experiment summarized in Table VII is considered. The F-value from table at 5% significant level F(0.05,1,8) =5.32

TABLE VII ANOVA

ANOVA									
DESCRIPTION	Source of Variance	Sum of Square	Degree of Freedom	Mean Square	Fo(Calu)	C%	Rank	F -TABLE VALUE F(0.05,1,8)	5% Significance level
VISCOSITY OF PAINT	A	0.069	1	0.069	0.46	0.23	5	5.32	NS
PRESSURE	B	0.422	1	0.422	2.81	1.41	2	5.32	NS
AIR COMPRESSOR	C	27.76	1	27.76	185.07	92.88	1	5.32	S
GUN DISTANCE FROM WORK PIECE	D	0.2363	1	0.2363	1.58	0.79	3	5.32	NS
VISCOSITY OF PAINT+PRESSURE	AB	0.0562	1	0.0562	0.37	0.19	6	5.32	NS
VISCOSITY OF PAINT+GUN DISTANCE	AD	0.0424	1	0.0424	0.28	0.14	7	5.32	NS
PRESSURE+GUN DIST FROM WORK PIECE	BD	0.1018	1	0.1018	0.68	0.34	4	5.32	NS
	Error(pure)	1.2	8	0.15		4.02			
	TOTAL	29.9	15			100			

From ANOVA table only one factor C is significant. It will contribute about 92% of total variation. The optimal level for the significance factors are selected based on the mean (avg) response. For maximization of response, the optimal condition is C2, B2 and D2.The above result is same for two methods.

III. RESULT AND DISCUSSION

This part is divided into three sections. It starts with the OA experimental results and interpretation of results. The next section shows the results of experiment verification using ANOVA. Thus, it can be concluded that the Air compressor is significantly affect the painting process. After verification, it will contribute about 92 % of total variation. For NS (Non significant) factors, levels are selected based on economic criteria.

A. Experimental result and Analysis

All four main factors are kept at level 2 and repeat the experiment. It will provide maximum paint coverage compare to previous stage. For example in earlier stage, golden yellow paint per liter coverage is 3sq m/lt. After conducting the design of experiment it will improved 6 sq m/lt. From equation (1) we conclude the predicted optimum response is 7.22.

We maintained all factors at level 2, the predicted optimum response is given below.

$$\mu_{predicted} = Y + (C_2 - Y) + (D_2 - Y) + (B_2 - Y) \quad (1)$$

$$= C_2 + D_2 + B_2 - 2Y$$

$$= 7.22$$

B. Calculation of change in operation cost

The company wants to minimize the paint cost at the same to maximize the coverage. So we recommend using a high level of Air compressor (3 HP) and low level of other factors. Because other factors are not significance at α=0.05.

For example we are choosing a beam having a painting area 8 sq m.

Paint chosen for testing: Golden yellow paint

Method applied: Design of Experiment using Taguchi (OA)

Test Result: Coverage has been increased by 3 to 6 Sq m/ lt.

Cost Save: Per litre, we are saving paint cost alone up to 150

TABLE VIII COST COMPARISON

DESCRIPTION	TOTAL AREA	PREVIOUS STAGE	CURRENT STAGE	DIFFERENCE
BEAM(Sq.m)	8	3	6	3
COST/LTR (Rs)	140	350	196	154

IV. CONCLUSION

The performance of painting process in steel structures can be enhanced by carefully selecting the factor level. For minimize the excess consumption of paint, we are concentrate about Air compressor and viscosity of paint. Remaining factors are selected based on the economic criteria. The recommended process condition gives

- Increase the efficiency of the process
- Improve the coverage
- Reduce the paint cost

However the process parameter and tested level in this work were set under company constraints. The result can be applied only to the similar process.

For future research, this work can be extended to working standards and manuals for different type of paint (Epoxy) in different colour.

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