Manufacturing Optimization of Reclaimed Rubber using Taguchi Method

B Manoj Kumar [1], R. Saravanan [2], P. Shanmugha Sundaram [3]
[1] Research Scholar – Mechanical Engineering, Karpagam University, Coimbatore, Tamil Nadu State, India,
[2] Dean & Head - Mechanical Engineering, Sri Krishna College of Technology, Coimbatore, Tamil Nadu State, India,
[3] Head - Automobile Engineering, Karpagam University, Coimbatore, Tamil Nadu State, India,

***Abstract*— Ever since the growth of automobile industry, there has been the problem of scrap tires. Global environmental concerns, resource reduction, and economic factors motivate the possibilities of recycling scrap tires. Rubber recycling processes keep developing, aiming at the re-utilization of rubber as close as possible to its virgin form. This type of recycling method where rubber is re-used like in its virgin form is called devulcanization or reclaiming. It is the process by which the scrap tire is converted into a state, which can be processed, compounded, mixed for further use by using the devulcanization principle. In this paper, the various input parameters which influence the reclaiming process are analyzed using Taguchi methodology. The Taguchi method is used in this paper to formulate the experimental work, analyze various parameters involved in reclaiming and to predict the optimal parameter of reclaiming. It is found that these parameters have a significant influence on quality of reclaimed rubber such as Mooney viscosity, tensile strength. The analysis with the help of Taguchi method also reveal the contributions of various input parameters involved in the reclaiming process in the Mooney viscosity, Tensile strength.**

Keywords— ***scrap tire rubber, Rubber recycling, Reclaiming, Taguchi method, Minitab 16***

I. INTRODUCTION

Reclaimed rubber is the product resulting from the treatment of used rubber tires, tubes and miscellaneous waste rubber goods by the application of heat and chemical agents, followed by intense mechanical working [1]. The target is to regenerate the rubber with its original plasticity so that it can be processed, compounded and revulcanised for further use. The principle of this process is devulcanization. First the whole tires are crushed into a particular mesh size after removing the steel and fibre from it. The buffing powder is mixed with certain chemical agents, which is then fed for reclaiming continuously in a reclaimator with certain temperature for a particular devulcanization time.

The various parameters which influence the reclaiming process are temperature, reclamation time and material. Usually the chemical compositions such as moisture content, acetone extract, carbon content, and ash content are the important parameters of material.

Taguchi techniques are experimental design optimization techniques [2, 3] which use standard `Orthogonal Arrays' for forming a matrix of experiments in such a way to extract the maximum important information with minimum number of experiments. As compared to any of the other experimental optimization techniques Taguchi techniques, uses least number of experiments and time for testing various parameters. Moreover Taguchi techniques, provides all the necessary information required for optimizing the problem. The main advantage of Taguchi Techniques is not only the smallest number of experiments required but also the best level of each parameter can be found and each parameter can be shared towards the problem separately. The Taguchi Method is used into determine the quality characteristics and design parameters, designing and conducting various experiments, and analysing the results to determine the optimum conditions.

II. PROBLEM DESCRIPTION

This section describes the specific problem. Normally the quality of reclaimed rubber is used to tell in terms of tensile strength and Mooney viscosity. In order to produce consistent quality of reclaimed rubber the various parameters of reclaiming such as temperature, reclamation time and material has to be optimised. Lower Mooney values creates problem of material sticking to mixing and calendaring equipment, while higher Mooney values lead to improper dispersion of ingredients, higher mixing times, etc.[4] Also reclaim with higher physical properties naturally helps in retaining the properties of the compound and higher dosage of reclaim can be considered for many applications. Hence optimal solution of various input parameters is necessary for maintaining the quality of reclaimed rubber in the recycling plants.

III. EXPERIMENTAL SETUP

Company chosen for the experimental work here is a National stock exchange listed tire recycling company in India located in the southern part of the continent running continuous production line with single screw extruder reclaimator process for recycling used truck tires. On an average the raw material (buffing powder) required for recycling is 10 ton per day. Using the extruder for continuous operation in the company, the production steps, labour cost and time can be reduced.

One of the first continuous reclaiming processes developed; made use of a “reclaimator”, [5] which in essence is a single screw extruder with a feedstock of 0.6 mm ground, fibre-free rubber scrap. In order to introduce high shearing action to the bulk of the material at elevated temperatures the clearances of the flights of the screw to the wall are set optimized, minimal values. The rubber is subjected to high shearing action between the screw and the wall of the extruder barrel. The end of the extruder is cone shaped. Only the material that has been well plasticized will be able to pass this cone.

IV. DESIGN OF EXPERIMENTS

In this paper Taguchi Method of experimental design is using in order to solve the problem. This method uses orthogonal arrays, which can stipulate the way of conducting the minimal number of experiments, which could give the full information of all the factors that affect the performance parameter [6]. The orthogonal array experiments are used here since they allow the simultaneous variation of many parameters and also the investigation of interactions between various parameters are possible. Statistical analysis, such as analysis of variance (ANOVA), is then employed to determine the relationship between the processing conditions and the response value, for example, Tensile strength and Mooney viscosity. The main advantage of the Taguchi method is that the number of experiments conducted in most of the cases is lesser than that of any other experimental design method using a statistical approach. Later regression analysis has been done to form the optimal solution of the problem. We have used minitab16 software throughout the paper.

According to the Taguchi design concept L27 orthogonal array is chosen for the experiments as shown in Table 1. In this study, the observed values of Temperature, reclamation time and material are set at three levels. Each experimental trail is performed as per L27 table and the optimization of the observed values is determined by comparing the standard method and analysis of variance (ANOVA) which is based on the Taguchi method. The control parameters and levels are mentioned in Table 2.

TABLE 1 ORTHOGONAL ARRAY FOR L27 DESIGN

L 27	**Level 1**	**Level 2**	**Level 3**
1	1	1	1
2	1	1	1
3	1	1	1
4	1	2	2
5	1	2	2
6	1	2	2
7	1	3	3
8	1	3	3
9	1	3	3
10	2	1	2
11	2	1	2
12	2	1	2
13	2	2	3
14	2	2	3
15	2	2	3
16	2	3	1
17	2	3	1
18	2	3	1
19	3	1	3
20	3	1	3
21	3	1	3
22	3	2	1
23	3	2	1
24	3	2	1
25	3	3	2
26	3	3	2
27	3	3	2

TABLE 2 CONTROL PARAMETERS AND LEVELS

Control	**Level 1**	**Level 2**	**Level 3**
Temperature (in degree Celsius)	110	120	130
Reclamation Time (in Seconds)	240	252	265
Material	1	2	3

TABLE 3 CHEMICAL COMPOSITION OF MATERIAL

Material	Moisture content (in %)	Ash content (in %)	Carbon content (in %)	Acetone extract (in %)
1	0.41	2.3	20.18	8
2	1.16	4.14	26.09	10.5
3	1.92	5.99	32	13

Table. 3 gives the chemical composition of material 1, 2 and 3 used in this problem. Even though Organised Reverse Logistics network has been used to collect material 1, 2 and 3, the chemical compositions of material is different as mentioned [7]

The Taguchi method uses a statistical measure of performance called signal to noise (S/N) ratio. Noise is referred to as any cause of variation such deterioration of equipment or any factor that is too expensive to control. While "signal" represents the desired target for the final good product or process. It takes both the mean and variability into account. This is a performance measure to choose control levels that best cope with noise.

V. DATA ANALYSIS

In this study, the objective is to determine the effects of the parameters of reclaiming, to perform the analysis of variance (ANOVA) and to establish the optimum conditions based on the Taguchi method. The performances of the reclaiming can be calculated for each experiment of the L27 by using the observed values. Table 4 lists the ANOVA test results for tensile strength of reclaimed rubber. From the table it is clear that temperature plays the vital role in tensile strength followed by reclamation time and material

TABLE 4 TENSILE STRENGTH RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS CONSIDERING LARGER IS BETTER

Analysis of Variance for Tensile Strength using Adjusted SS for Tests; S = 1.03638, R-Sq = 96.20%, R-Sq (adj) = 94.51%

Level	Temperature in degree Celsius (A)	Reclamation time in seconds (B)	Material (C)
1	35.72	35.15	34.91
2	34.83	34.94	34.97
3	34.21	34.66	34.88
Delta	1.51	0.49	0.09
Rank	1	2	3

TABLE 5 MOONEY VISCOSITY RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS CONSIDERING NOMINAL IS BEST (10*LOG10(YBAR**2/S**2))

Analysis of Variance for Mooney viscosity using Adjusted SS for Tests ; S = 1.17063, R-Sq = 86.15%, R-Sq (adj) = 79.99%

Level	Temperature in degree Celsius (A)	Reclamation time in seconds (B)	Material (C)
1	27.17	25.39	27.86
2	29.4	29.7	31.63
3	30.42	31.91	27.51
Delta	3.25	6.52	4.12
Rank	3	1	2

Table 5 lists the ANOVA test results for Mooney viscosity of reclaimed rubber. From the table it is clear that reclamation time plays the vital role in Mooney viscosity followed by material and temperature

VI. RESULTS AND DISCUSSION

Figure 1 shows the effects of efficiency of each factor for various level conditions in Tensile strength. From the figure, it is clear that, temperature and time plays very dominant role in tensile strength. Less temperature in the heating zone of reclaimator produces high tensile strength. Similarly less reclamation time in reclaimator gives higher tensile strength. The material does not have a significant role in tensile strength. It may be due to the organised structure of material collected through a particular route.

Fig. 1 Effects of various parameters on tensile strength

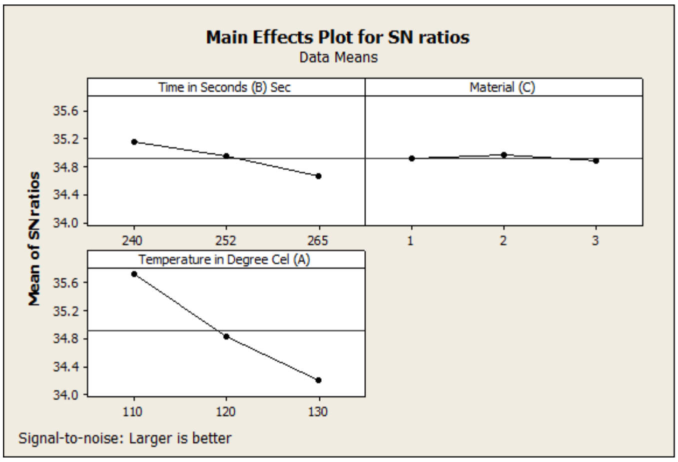

Fig.2 Effects of various parameters on Mooney viscosity

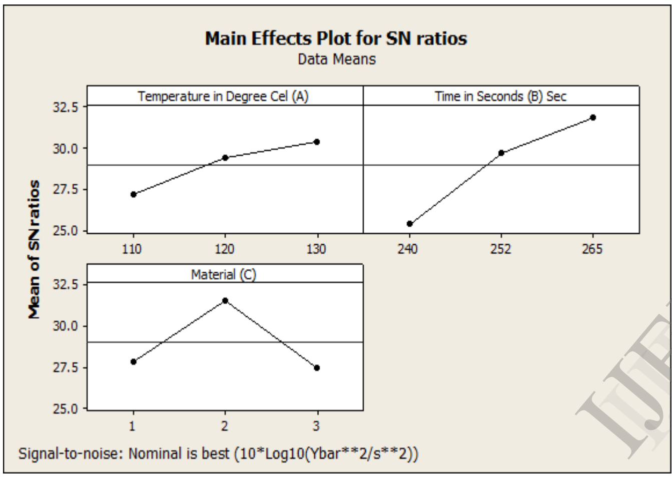

Figure 2 shows the effects of efficiency of each factor for various level conditions in Mooney viscosity. From the figure, it is clear that all factors such as temperature, time and material play equally important role in Mooney viscosity. Medium temperature in the heating zone of reclaimator produces nominal Mooney viscosity. Similarly medium reclamation time in reclaimator gives nominal Mooney viscosity. The material 2 compositions give nominal Mooney viscosity.

Regression Analysis equation of tensile strength:
Tensile Strength (Kgf/cm2) = 147 - 0.489 Temperature in Degree Cel (A) - 0.129 Time in Seconds (B) Sec - 0.167 Material (C) (1)

Regression Analysis equation of Mooney Viscosity:
Mooney Viscosity = - 27.2 + 0.250 Temperature in Degree Cel (A) + 0.0971 Time in Seconds (B) Sec - 0.083 Material (C) (2)

VII. CONCLUSION

The results obtained for investigating the optimization of reclaimed rubber after conducting the experiments are summarized as follows.

The experimental results show that contributions of working parameters such as temperature, reclamation time play an important role in the reclaim process focussing the tensile strength of reclaimed rubber. Less temperature and less time in the reclaiming process create high tensile strength in reclaimed rubber. The experimental results show that the contributions of working parameters such as temperature, reclamation time, and material equally play an important role in the reclaim process focussing the Mooney viscosity of reclaimed rubber. Medium temperature and medium time in the reclaiming process create nominal Mooney viscosity in reclaimed rubber. The regression analysis equation of tensile strength (1) and Mooney viscosity (2) has been formed. Taguchi optimal solutions give the better results for reclaiming process and it also reduces the number of experiments that are required for finding its performance metrics.

VIII. REFERENCES

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