Productivity Improvement of Rubber Roller Mixing Process using Cause and Effect Analysis: A case study

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Abstract—Productivity plays an important role in any industry which enables a firm to compete in a competitive global world. Productivity provides an idea about how efficiently resources in a company are utilized. This paper addresses the application of cause and effect diagram for a mixing process of rubber roll manufacturing. Rubber roll is an essential component which is used in a textile, plastic, rayon, paper mill and printing industry. For a product to have a good quality, the product should be made with standardize process and with consistent quality. Rubber roll and other rubber products are made by mixing process of various ingredients within specific temperature limits. The purpose of this paper is to examine the rubber roll manufacturing process for productivity improvement. The concept of work study for detailed observations is used to improve the productivity. The mixing process is taken into consideration, by taking number of trials, problem related with the mixing process are identified. Corrective actions are taken to improve the effectiveness of the equipment used for mixing process. Based on the observations, a detailed cause and effect diagram is constructed. With the help of this study and after the necessary modifications, the goal is achieved by a proposed standardized mixing process, which in turn leads to productivity improvement.

Index Terms—Rubber manufacturing process, Work study, Method study, Cause and effect diagram.

I. INTRODUCTION

Rubber coated rolls, blanket and rubber lining (e.g. natural rubber, SBR, Nitrile rubber, Neoprene, EPDM, silicone and Hypalon) are an important component used in paper mill, textile, plastic, rayon and chemical industry. In rubber roll industry for making a rubber roll or rubber lining, formation of rubber compound is an important task. These rubber products are made by mixing of different ingredients which provides specific properties to the final product. Depending upon the end use of rolls and temperature conditions, the rubber has to be compounded with different ingredients. Rubber compounding is carried out to provide desired physical properties, like hardness, resilience, elasticity and tensile strength to the final prepared compound.

The first step in manufacturing of any rubber product is to knead the rubber between rollers and the process of softening by mechanical shearing of rubber which is also known as mastication. Natural rubber in its ideal state has high viscosity therefore any ingredients used for enhancing the rubber property is unable to mix with the rubber and by mastication process natural rubber is soften and its viscosity and molecular weight reduces. Thus allows ingredients to be mixed homogeneously with rubber. The mixing process is basically done on two machine a) Open mixing mill and b) Kneader machine.

Open mixing mill: A mixing mill consists of two hollow metal cylinders (rolls) placed horizontally and rotating towards each other as shown in Fig. 1. The two rolls are revolving with different speed where front roll rotates slower than the back roll. The difference in speed of two rolls is called as friction ratio. Rubber is masticated due to shearing action between the two rolls and friction ratio allows this shearing action at nip to disperse different ingredient with rubber and to hold the rubber compound on one roll that is front roll.

Kneader machine: It is basically a closed chamber mixing machine as shown in Fig. 2. It has two rotor which operates at a slight differential speed. Mixing of rubber and ingredients occurs between the rotor and sides of chamber. The ingredients are loaded from top opening of chamber. Pressure is applied by the ram which closes the opening gate of the chamber. Shearing action of ingredient and rubber is done by two rotors and side walls of the chamber.

The mixing process was reviewed at rubber roll industry. Process flow chart of rubber roll manufacturing
In this paper, mixing process of rubber compounding is studied for making a rubber compound on open mixing mill and kneader machine. Research paper includes the basic process of preparing rubber compound. Cause and effect analysis of mixing process on open mixing mill and kneader machine and remedies to increase the productivity of mixing process. [1] Productivity is the ratio of output and input. Higher productivity provides higher standard of living including larger supplies of consumer goods and capital goods at lower cost, higher real earnings, improvement in working and living conditions and strengthening of economic foundation of human well-being.

II. LITERATURE REVIEW

M. Tapiwa et al. [2] used work study technique to optimize the manufacturing plant maintenance process for a fertilizer manufacturing plant. They have shown the relationship between the plant maintenance management principle and the ergonomics which imparts better maintenance workspace for the worker. They have also developed charts for workforce versus productivity of plant and recommended the future scope and possible changes for engineering, production and the support sections. Authors have highlighted the main areas of improvement in fertilizer manufacturing plant maintenance system by updating the work space for maintenance, improved efficiency, and product quality and reduced downtime.

I. Bhiradi et al. [3] used work study technique to improve productivity of a heavy machine shop. They studied rear covering housing line, differential housing line and gear box housing line of a tractor. They calculated the cycle times of each machine in different assembly and manufacturing lines. They used method study for preparing time study sheet. After critical examination and the analyzing the data of time study of exiting method, they proposed a new method after eliminated all the non-value added activities and improved the productivity by 35% of the system.

C. Duran et al. [4] used the technique of time and motion study for calculating process time of a tea glass manufacturing process. In this work, micro element study of tea glass process was carried out and subsequently the standard time of the process was established after analyzing the obtained data and by eliminating unwanted activities. After successfully implementation of the recommendations they achieved an overall improvement of 53%.

A. Mariajayaprakash and T. Senthivelan [5] have applied principle of cause and effect diagram, Taguchi method and Failure Mode and Effect Analysis (FMEA) for identifying the causes and its effects of failure occurring in a sugar mill industry. They have used the concept of Ishikawa diagram for listing the reasons of failures such as human, mechanical, electrical and temperature sensor failure. They used Failure mode and effect analysis technique for analyzing the failure occurred in cogeneration process in sugar mill and found the main parameter which affects the process. Concept of Taguchi method was used for reducing the failure in fuel feeding system of cogeneration process and for optimizing the process parameter.

A. Gunasekaran and P. Cecille [6] showed how the productivity of a small and medium scale industry can be improved. They took three aspects for improving the productivity, first aspect was improvement of tools used in the workstation, second aspect was implementation of kanban system between hose assembly and hose cutting workstation and last aspect was development of autonomous cell. They have also discussed about 5S and control of inventory level in order to have low capital carrying cost and proposed to have a customer oriented assembly line.

A. P. Puvanasvaran et al. [7] highlighted the method to improve overall equipment efficiency (OEE) of an autoclave operating process by using technique of time study. They performed two time study techniques, first by using stop watch to validate OEE standards and second technique was Maynard’s Operating Sequencing Technique (MOST) which is then revealed in terms of Value added and Non-Value added activities. They analyzed the data obtained and by eliminating unwanted activity contributed to reduce in cycle time of process. After evaluating the process, standard process sequence was driven and about 4.64% increment in efficiency was found without compromising the quality of product.

D. Boothby et al. [8] discussed about the increasing of companies’ productivity by providing exposure of new technology in the field of manufacturing and by providing training to operator to adopt new technique, which will help the firms to achieve better productivity and economic performance. Authors have created awareness about training programs which helps to enhance skill of a person working on machine and ultimately leads to better performance of a company.

A. R. Sharma [9] described about the compounding techniques used for making a rubber compound, which is further processed to form a rubber tire. He identified various controllable factors like batch size, rotor speed, sequence of addition, mixing time, ram cylinder pressure, temperature of the mixer, finished mix and discharge speed and subsequently he performed the experiment and found its effect on production. He also discussed about further processing of rubber compound to final product tire.
D. P. Mishra et al. [10] show how productivity of a coal mine industry can be improved. Authors have applied Time and motion study technique for data collection of mining process. They have identified the factors affecting the cycle time and productivity of coal mine such as cycle time of operation, manpower allotment and machine efficiency. They analyzed the collected data and then unwanted processes were eliminated for reducing the overall operation time. They have also highlighted the measures for reducing breakdown of machine.

N. U. I. Hossain et.al. [11] have applied principles of fishbone diagram, total quality management and control charts to improve quality in a pharmaceutical company. They developed fishbone diagram for weight variation and thickness variation of tablet and analyzed the data of Cefotil 500 tablet for weight variation and thickness variation and plotted control charts showing upper control limit and lower control limit and calculated variance of defects arising in tablet. They discussed about possible changes required in order to lower the waste due to defective tablets.

M. Hekmatpanah [12] described how the potential causes in an oil company can lead to major problem and how the waste in the company can be reduced using technique of fishbone diagram and six sigma. He used fishbone diagram to represent the cause and effect of production line of capping and filling process. He also conducted FMEA of plate cutting section and developed fishbone diagram and analyzed data of plate cutting process and prepared Pareto chart. After evaluating the process and eliminating the causes of potential defect, the generation scrap is reduced from 50000 ppm to 5000 ppm.

N. Patel [13] utilized time study technique to monitor the production in a bearing manufacturing company. He determined the standard time for each process involved in a bearing manufacturing industry and applied concept of OEE tool for each process to measure performance of equipment per shift. He analyzed and evaluated the collected data and then by eliminating non value added activity, finishing time and spark out time of the process were reduced. He proposed the use of auto cone checker to detect the missing roller instead of manual cone check to reduce inspection time per bearing assembly for improving the overall productivity.

III. METHODOLOGY

A Pilot study was carried out to observe and understand the whole mixing process of rubber compounding. Work study of rubber compounding on kneader machine and open mixing mill was carried out. After work study of mixing process, all the observations regarding mixing process was analyzed in terms of value added, non-value added and idle time of man, machine and material. Based on the work study, a detailed cause and effect diagram was developed. Factors affecting the causes of low production and inconsistent quality were identified and corrective actions were taken to ensure good quality product and then accordingly mixing process on kneader machine and open mixing mill was revised.

A. Process description of mixing process on mixing mill

1) Set nip roll opening to 2 mm (thinning) and maintain roll temperature up to 40-45°C.
2) Add rubber to mill nip and allow it to band as a continuous sheet on front roll.
3) Make ¾ cut from both side of roll with hand knife and allow rubber to pass through nip till smooth rolling bank is formed on nip.
4) Set the nip opening to 3 mm (thickening) and add sulphur to masticated rubber then allow it to roll till it get properly mixed with rubber.
5) Add antioxidant to rolling bank and make cut from both side of roll for proper mixing of ingredients.
6) Make cut from one side to other side, remove it and then place the bank in nip at other end of roll for homogenous mixing.
7) Add filler to rubber bank sequentially in three to four times in equal quantity.
8) Add processing additives like wax, polymer, blowing agent and tackifying agent.
9) Make a small cut from both side of the rubber compound after mixing of all ingredients.
10) Add lubricants like mineral oil, resin blends, fatty acid etc. Add reinforcing filler to the compound.
11) Add activators like zinc oxide, stearic acid according to the recipe of the compound and then allow the compound to mix properly.
12) Make a small cut from both side of rolling bank after adding heat resistive agent to the rubber bank, remove it and then feed to other side.
13) Allow the compound to mix properly till it get uniformity.
14) Add accelerator to rubber bank and make a small cut from both side of rolling bank.
15) Cut the compound, reduce the gauge between rolls and then cut the sheets from this gauge setting.
16) Cut the sheet from roll, remove it and feed it to roll nip. Repeat this step for 3 times.
17) Cut rubber through one side and remove it from roll, make nip setting thick. Feed rubber bank to nip and make small cuts and mix it properly.
18) Cut sheet of required length using knife and place sheet on the table one by one.
19) Cut two samples from sheet taken out of mixing mill and then write the details on sample like date, compound number, and batch number on sample. Send that sample for Rheometer test.
20) Send Second sample to autoclave for vulcanization process of 6-7 hrs. Grind the sample on grinding wheel for smooth surface finish and check the hardness by using Durometer shore A and shore D for soft rubber compound and hard rubber compound, respectively.

B. Process description of mixing process on kneader machine

1) Raise the ram and insert the elastomer into the mixing chamber.
2) Close the chamber with ram and cover and then allow the elastomer to disperse up to 1 minute.
3) Stop the machine and then raise the ram and subsequently tilt the chamber and add filler to the kneaded rubber.
4) Tilt the mixing chamber to its original position. Close the chamber with ram and cover and then start the machine.
5) Lower the ram into mixing chamber by its half stroke and allow compound to mix for 3 minutes.
6) Lower the ram till its full stroke and allow the ingredients to mix properly.
7) Stop the machine and lift the cover and ram. Add oil to the compound and close the chamber with ram and cover. Start the machine.
8) Lower the ram up to its half stroke and mix for some time.
9) Lower the ram till its full stroke and allow the ingredients to mix properly.
10) Stop the machine and lift the ram up to its half stroke, lift the cover and feed the powder spread on top of ram to mixing chamber.
11) Lift the ram to its full stroke and feed powder by cleaning on side of ram face to chamber.
12) Lower the ram and cover to its full stroke and start the machine and then wait for 2 minutes.
13) Place the tray near the discharge door. Lift the cover and piston to its full stroke.
14) Tilt the mixing chamber and discharge the compound in tray.
15) Tilt the mixing chamber to its initial position and stop the machine.
16) Wait for the mixing chamber to cool down for next batch.
17) Take the compound from tray and take out sheets by adding accelerator in compound and mix it on open mixing mill.
18) Cut two sample from sheet taken out of mixing mill. Write date, compound number, and batch number on sample. Send the sample to check quality in Rheometer.
19) Send the second sample in autoclave for 6-7 hours. After removing from autoclave the rubber gets hard.

IV. CAUSE AND EFFECT DIAGRAM

The cause and effect diagram is a tool to display graphically the causes of any problem. It is also called as Fishbone diagram or Ishikawa diagram. On the basis of the detailed observation made while carrying out method and time study on mixing mill and kneader machine, a detailed cause and effect diagram is developed.

The cause and effect diagram shows all the possible modes of causes for the defect and the factors which affects the quality of the rubber compound. With the help of cause and effect diagram, problems related with the inferior quality of the rubber compound can be easily traced and solved.

As explained in methodology, work study of mixing process on kneader machine and open mixing mill was carried out for AA75, AH39 compound and same procedure was followed for different compounds. A detailed cause and effect diagram was developed as shown in Fig. 4 and Fig. 5.

Observations identified during the method and time study and corrective actions taken for mixing process on open mixing mill are shown in TABLE I.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Observation</th>
<th>Remark</th>
<th>Action Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Breakdown of stock blender</td>
<td>Limit switch plunger jammed due to impact of rubber</td>
<td>Limit switch changed</td>
</tr>
<tr>
<td>2</td>
<td>Temperature of roll increases</td>
<td>Circulation of cooling water blocked</td>
<td>Thermocouple fixed at inlet and outlet unit of water</td>
</tr>
<tr>
<td>3</td>
<td>Raw rubber not available at workstation</td>
<td>Cycle time increases as waiting time of rubber is added to it</td>
<td>Temporary stock of rubber for two mixture kept at workstation</td>
</tr>
<tr>
<td>4</td>
<td>Variation in sequence of procedure</td>
<td>Quality gets affected</td>
<td>Sequence variation is rectified</td>
</tr>
<tr>
<td>5</td>
<td>Variation in use of stock blender</td>
<td>Cycle time varies</td>
<td>Stock blender used in each compounding</td>
</tr>
<tr>
<td>6</td>
<td>Jamming of cooling pipe</td>
<td>Pipe jammed due to rubber particle</td>
<td>Filter changed at foot valve of water pump</td>
</tr>
<tr>
<td>7</td>
<td>Mixing time is more</td>
<td>Roll nip kept less while mixing</td>
<td>Nip setting change</td>
</tr>
<tr>
<td>8</td>
<td>Mixing time is more</td>
<td>Fatigue of operator</td>
<td>Nip setting motorized</td>
</tr>
<tr>
<td>9</td>
<td>Heat built up in bushing of rolls</td>
<td>Insufficient lubrication</td>
<td>5 way valve changed, greasing hose changed</td>
</tr>
<tr>
<td>10</td>
<td>Undispersed chemical</td>
<td>Improper mixing</td>
<td>Proper mixing cycle</td>
</tr>
</tbody>
</table>

Observations identified during the time study and corrective actions taken for mixing process on kneader machine are shown in TABLE II.

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Observation</th>
<th>Remark</th>
<th>Action Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooling time of machine is more</td>
<td>Waiting time for next batch increases</td>
<td>Descaling and cleaning of mixing chamber</td>
</tr>
<tr>
<td>2</td>
<td>Mixing chamber cover lifting is slow</td>
<td>Pneumatic pressure is not uniform</td>
<td>3 way valve changed at FRL unit</td>
</tr>
<tr>
<td>3</td>
<td>Temperature drop of mixing chamber is slow</td>
<td>Non – uniform cooling</td>
<td>Strainer changed in cooling tower</td>
</tr>
<tr>
<td>4</td>
<td>Variation in sequence of procedure</td>
<td>Quality gets affected</td>
<td>Sequence variation is rectified</td>
</tr>
</tbody>
</table>

After implementing the suggestions provided for kneader machine and mixing mill, the results obtained are discussed in the subsequent section ‘result and discussion’.

V. RESULT AND DISCUSSION

The observations of analysis of mixing process and the improvement achieved on kneader machine are as follows:
Fig. 4. Generic cause and effect (fishbone) diagram for mixing process

Fig. 5. Generic cause and effect (fishbone) diagram for mixing process on kneader machine
a) As shown in Fig. 6, average idle time of man is reduced from 738 to 345 seconds.

Fig. 6. Comparison of idle time of man

b) Average value added time of man reduced from 635 to 470 seconds as shown in Fig. 7.

Fig. 7. Comparison of Value added time of man

c) Average non-value added time of man reduced from 595 to 332 seconds as shown in Fig. 8.

Fig. 8. Comparison of Non - value added time of man

d) Average machine idle time reduced from 188 to 10 seconds as shown in Fig. 9.

Fig. 9. Comparison of idle time of machine

e) Average machine non-value added time reduced from 425 to 314 seconds as shown in Fig. 10.

Fig. 10. Comparison of Non - value added time of machine

Takt Time Calculation (For Kneader Machine)

It is the rate at which a product is to be manufactured in order to satisfy the customer demand. Following steps are carried out to calculate the cycle time for making one rubber compound on kneader machine:

1. Total available time = 2 shifts per day * 25 working days in a month.
2. Demand per day = 36 Mixtures.
3. Available working time per shift = 450 minutes (Excluding lunch and tea break) = 27000 seconds
4. Available time per day = 27,000 * 2 = 54,000 seconds
5. Takt time = Total available time per demand = 54,000 / 36 = 1500 seconds (25 minutes) (Can be achieved)
From the past records of June - Nov 2015, the production of kneader machine was 12 mixtures per shift. After analyzing the cause and effect diagram of kneader machine, probable solutions were identified and implemented which are discussed in TABLE II. After implementation of the suggestions, the utilization of machine was increased as evident from the production data of Dec 2015 – March 2016 as shown in Fig. 11 and it is 15 mixtures per shift without compromising the quality in comparison to the earlier production of 12 mixtures per shift. The Takt time calculation shown above shows that the cycle time per mixture which can be achieved without affecting the quality of product and therefore 18 mixtures per shift can be made.

![Production per month (2015-16)](image_url)

Fig.11. Production detail of rubber compound on kneader machine (2015-16)

Takt Time Calculation (For mixing mill)

1. Total available time = 2 shifts per day * 25 working days in month.
2. Demand per day = 24 Mixtures.
3. Available working time per shift = 450 minutes (Excluding lunch and tea break) = 27000 seconds
4. Available time per day = 27,000 * 2 = 54,000 seconds
5. Takt Time = Total available time per demand / 2250 sec (37.5 minutes)

The available takt time for open mixing mill is 37.5 minutes per compound. Since the time for each compound is different i.e. it may be less or even more than the available takt time, hence the proposal of making the compounds which have similar production cycle time for production can be taken together and the production per shift should be based on the production cycle time for that particular shift. In this way the overall weekly production requirement can be met.

For mixing process on kneader machine, after the analysis of the cause and effect diagram, problems related with the equipment as well as human error were identified and resolved which resulted in increase of production of kneader machine from 12 mixtures per shift to 15 mixtures per shift and by providing proper training to the operator it can be increased up to 18 mixtures per shift. Another study was also carried out on different mixing mill and after time study; the problems related with the breakdown of machine and human error were rectified. A proposal for attachment for nip setting on mixing mill was made, which will reduce the fatigue in operator.

VI. CONCLUSION

In this case study, time study was performed for kneader machine and mixing mill. The time study data were analyzed in terms of man, machine and material chart and non-productive and redundant activities were eliminated. From the time study of kneader machine it was found that the machine takes more time between productions of two batches due to slower cooling of mixing chamber. Therefore, a detailed cause and effect diagram for the mixing process was prepared and problems related with equipment and human error were rectified. Mixing process on kneader machine and mixing mill was revised. A proposal for attachment for nip setting on mixing mill was made, which will reduce the fatigue in operator. After implementing necessary changes in machine, production of kneader machine increased from 12 to 15 mixtures per shift which can be further increased up to 18 mixtures by providing the proper training to the operator. A proposal of producing one particular compound on one machine per shift was made which helps in better utilization of the machine with increase in production with less number of days.

REFERENCES


