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Development of Oring Material for Aftermarket Application Using Six Sigma Processes

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Abstract

This is a fictitious project created to understand the basics of six sigma and its application in real world. The project is shaped primarily using six sigma methodologies to improve the efficiency of the existing processes, develop a new O-ring material for aftermarket applications that would satisfy all the stake holder requirements and improve bottom line of the company. Design approach: Based on the class works study and literature reviews, the project proposes a process flow map of the six-sigma application in a braking system manufacturing unit. The methodology applied here is DMAIC processes. Various statistical tools and techniques used at various levels to establish process capabilities before and after the application of the project.

Keywords
Six sigma, manufacturing industry, DMAIC

1. Introduction
Six Sigma is a set of techniques and tools used to reduce defects and improve processes. Sigma is a term (Greek) used in statistics to represent standard deviation from mean value, an indicator of the degree of variation in a set of a process. Sigma measures how far given process deviates from perfection. Higher sigma capability, better performance. The project under study is a braking system manufacturer who designs the product, manufacturers the whole assembly and dispatch to the original vehicle manufacturer. Growing competitiveness in the market leads to cost driven design of products and manufacturing processes. This project aims to reduce the cost of a relay value assembly for aftermarket application through a systemic six sigma process called DMAIC. (**D**efine, **M**easure, **A**nalyze, **I**mprove and **C**ontrol)

2. Literature Review
A literature review was conducted to understand the answers of various questions that raised. Some of those are, how various six sigma projects were being executed in real time environments. How the key performance measures were established. How those established measures were being measured at various phases of the project. Finally, understanding usage comprehensive statistical and non-statistical tools.

Eckes (2001) mentions eight six sigma steps to strategic improvement in his book of “The Six Sigma Revolution”. Those eight in order as creation and agreement of strategic business objectives, creation of core, key sub-, and enabling processes, Identification of process owner, creation and validation of measurement dashboards, data collection on agreed dashboards, creation of project selection criteria, Using the project selection criteria for project selection, Continual Management of Processes to Achieve Strategic Objectives of the Organization. “Six Sigma is a programme that combines the most effective statistical and non-statistical methods to make overall business” stated by Breyfogle, (2003).

Various statistical tools are used in real world situations. Antony, et al. (2006) explained in detail few concepts of the five step hypothesis testing’s which includes specifying the Null Hypothesis. Specifying the Alternative Hypothesis, set the significance Level (a), calculate the Test statistic, Corresponding P-Value and finally drawing a Conclusion. Cavanagh, et al. listed few real time case studies of projects executed at companies like GE, Motorola.

Few non statistical tools are used in the project including a kind of brain storming exercise. Pyzdek. and Keller explains the use of CTQ tree analysis which were used in this project. It states CTQ as a diagram based tool used to translate broad customer needs into specific, actionable, measurable performance requirements.

Kubiak and Benbow explain various certification processes existing, and along with a deep insight of black belt certification programme. The handbook lists at the project level, there are black belts, master black belts, green belts, yellow belts and white belts. These people conduct projects and implement improvements. Black Belt: Leads problem-solving projects. Trains and coaches project teams.

Green Belt: Assists with data collection and analysis for Black Belt projects. Leads Green Belt projects or teams.

Master Black Belt: Trains and coaches Black Belts and Green Belts. Functions more at the Six Sigma program level by developing key metrics and the strategic direction. Acts as an organization's Six Sigma technologist and internal consultant.

Yellow Belt: Participates as a project team member. Reviews process improvements that support the project.

White Belt: Can work on local problem-solving teams that support overall projects, but may not be part of a Six Sigma project team. Understands basic Six Sigma concepts from an awareness perspective. "A Cause and effect Matrix is a tool to help the Six Sigma team prioritize the X's or process inputs. The Cause and Effect Matrix relates Process Steps to Process Inputs (X's) and correlates the Inputs to Process Outputs. In a C&E Matrix, Customer Requirements (or Y's) are ranked by order of importance to the Customer. The Inputs (X's) and Outputs are rated by their Interaction. The Cause and Effect Matrix should determine what Key Process Input Variables (KPIV's) should get the most attention."; as mentioned in "isixsigma" tutorial course material on six sigma topics. Various six sigma related sources and authors emphasis that the initiation for any six-sigma project has to be from the strategic business objectives and the closing of the project shall confirm the tangible benefits that meets those objectives.

I. Project Background

The project is framed on a braking system manufacturing unit at Chennai, India. The main focus of the unit is design, manufacture key parts, and outsource child parts and assembly of total braking system. The item which is focused on this project is a relay valve assembly which comprises of O-rings, body, shaft and end covers. The relay valve operates as a remote-controlled direction control valve that apply or releases air to the brake chambers based on the control signal from the foot brake valve or other source. The primary function of relay valve is to speed up the application and release of rear axle(s) brakes. One of the business objective was to reduce the manufacturing cost of relay valve assemblies for aftermarket applications. It has been observed that the cost of manufacturing for OE parts as well as for aftermarket (AM) or service level parts are same. Oring is one of the functional part of the relay valve assembly. In theory the life of the O-ring shall be considered as the life of the relay valve assembly, once the O-ring fails or start leaking the whole assembly would be replaced in real life due to the complication involved in assembly of the relay valve. The primary function of the O-ring is effective sealing during piston movement. The part is named as piston O-ring. Why the focus on the O-ring in this project is explained in the define phase of this paper.

II. Application of Six sigma DMAIC methodologies

The methodology adopted must be comprehensive and shall cover all possible causes of problem. The solution to the problem would be inappropriate if the methods are not comprehensive enough. A high level Six sigma DMAIC process map was prepared in a sequential manner, presented here in "Figure 1" and the same were followed further until completion of the project. The process map includes all the five phases of DMAIC methodology namely Define, measure, analyze, improve and control and the same were successfully implemented to achieve the business objective of reducing cost of relay valves for aftermarket applications. A 15 step process map were established and appropriate tool which were used during each phase were listed for easy understanding. Few tools which were used were CTQ analysis, a project charter, QC tools like pareto chart, "Gage R&R" study for measurement system analysis, "cause and effect analysis" for brain storming exercises. Few statistical tools including a design of experiment were also being conducted to prove the project statistically. Activates that were planned and executed were listed below phase wise starting from define phase.

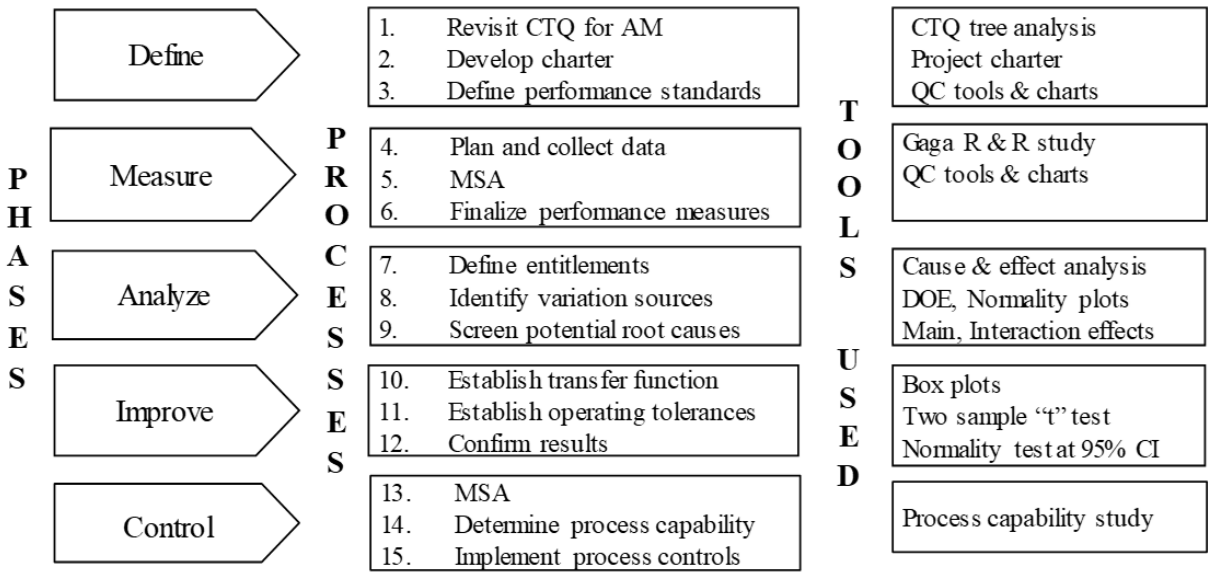


Figure 1. DMAIC process map

Define phase

Having complete understanding of customer's requirements, defining the problem clearly quantitatively as well as qualitatively is the key objective of this phase. A CTQ tree was revisited exclusively for aftermarket applications. Various parameters like design and appearance, price performance ratio, function of the part at vehicle level, life of the product was being analyzed. Based on the CTQ analysis, it was observed that the life of the product exceeds customer requirements for AM. For OE the life of relay valve was established to 1 million (m) cycle and for AM based on competitor's data and customer's VOC information, the target set between 0.5 m – 1 m cycles for AM application. An image of CTQ tree is presented in "Figure 2".Based on reducing the life of the relay valves for AM, a Pareto were made to see the part wise cost contribution to the whole assembly. Refer "Figure 3" for pareto chart. It was observed that though the O-ring contribution to overall valve cost is less, the life of the relay valve assembly depends on the life of the O-ring. In general, other hard parts like piston, end covers has a substantial life of 3 m cycles. Based on CTQ analysis it was observed that there exists scope for re-engineering of the whole relay valve assembly for Engineering department which might fall in to DFSS, adding new variants which went in to study for manufacturing department etc. The scope of this project is limited to further study of piston O-rings.

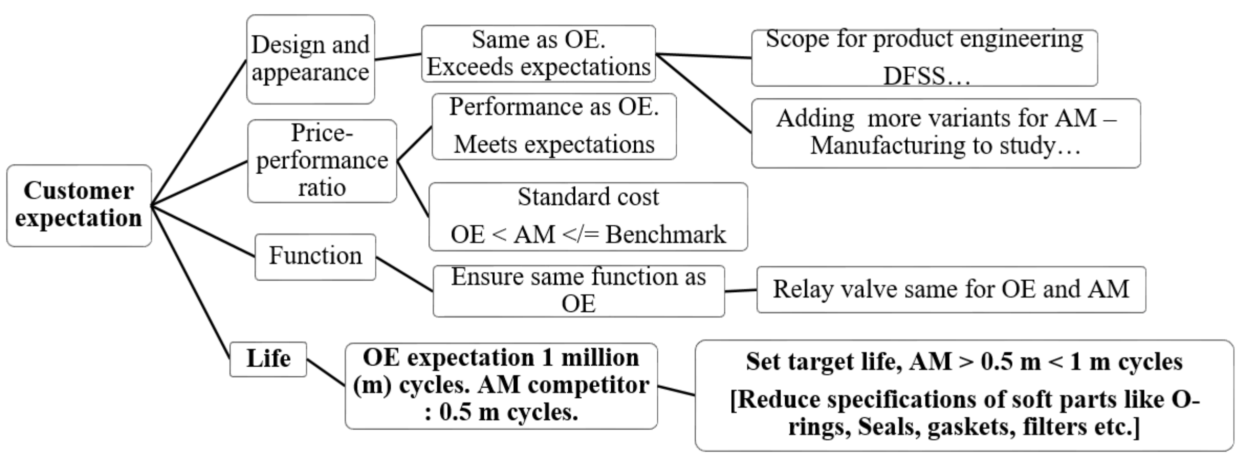


Figure 2. Voice of customers

An accelerated endurance testing was being carried out to confirm existing O-ring life in m cycles. It was observed that the leak started at 1.3 m cycles during the test, competitor O-ring leaked at 0.45 million cycles itself. This confirms that the Oring was manufactured above expectations for AM. Further cost breakdown data of O-ring confirms 68% of the total cost of O-rings comes from rubber material alone. Further with all the available data a project charter was created in detail, refer table.1 for the charter developed to understand the overall effect of the project. Based on the outcome, the project performance standard were established. *"Develop a new piston O-ring material for AM application"* with target life between 0.8 – 1.3 m cycles, with no functional degradations and finally to improve cost of the part.

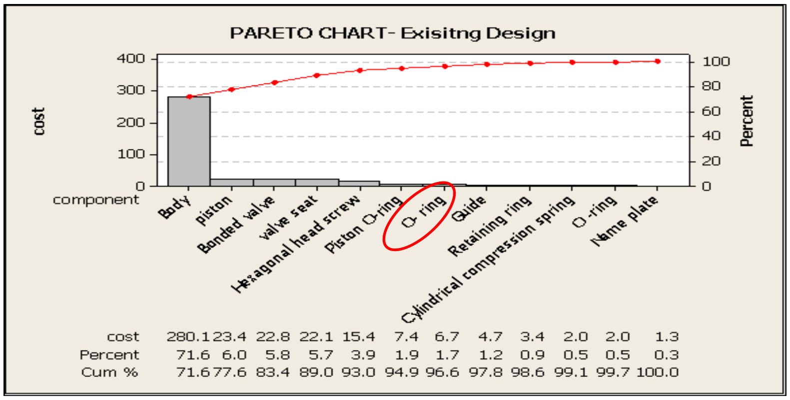


Figure 3. Pareto Chart

Table 1. Project Charter

Understand the problem (5W2H):	
What is the problem?	O-ring material over specification for aftermarket application
Why is it a problem?	Initial understanding was OE = AM
Where was it detected?	Aligns to KPI on reducing cost for relay valve AM application
Who detected it?	Engineering
When was it detected?	
How was it detected?	During competitor bench mark analysis and further VOC
How many? Or How much?	
Project Objective: BIG Y	Achieve the consistent O-ring Life 0.8 million cycles lower than OE life cycles (1.3 million) better than competitor device
Benefit to the Customer	Product optimization, life cycle better than AM Competitor
Expected financial Project Impact	Expected annual benefit on Relay valve O-rings : 36K $ Horizontal deployment : 26 k $
Functional Areas/ support required	
Define: Competitor Device bench marking	Marketing
Measure: MSA	QA
Analyze: Identify significant X	CFT team
Improve: DOE	O-ring supplier, QA
Control:	CFT team

A. *Measure phase*

A detailed snap shot of O-ring manufacturing process starting from raw material mixing to molding and deflashing is shown in "Figure 4" The core of rubber parts is the compounding process. Natural rubber is mixed with a lot of fillers, curatives, chemicals, colorants etc. to satisfy various properties including mechanical properties like tensile, compression; Ozone properties; flow properties; rheo properties etc. Basically, a formulation is being prepared to meet requirements, then all the raw materials are mixed together proportionately which is called compounding process. Later the materials are made into required sizes and shapes as fillets, introduced into traditional rubber molding process. One of the properties which defines the life of the O-rings is the compression set property called CS hence forth. It defines the permanent deformation of the material when force is removed, given in %. In general, higher the CS % the material is harder and lesser the softer. With a specific protocol this CS is measured in 2 ways. CS-A and CS-B. In order to meet the reduced life of O-ring it is essential to establish target value of compression set. Compression set of existing parts were measured 15% when compared to specification of 81%. So, target value for CS on piston O-rings shall be above 15% and below 80%. Refer “Figure 5” showing the scope for CS improvement. Ideally, CS shall not be changed radically as the difference has significant impact on other functional parameters. A measurement system analysis was conducted for dial thickness gauge instrument with which the trial parts were planned to be measured. Refer “Figure 6” for the measurement system analysis study. Total Gage R&R study variation resulted with 13% that falls within agreeable level.

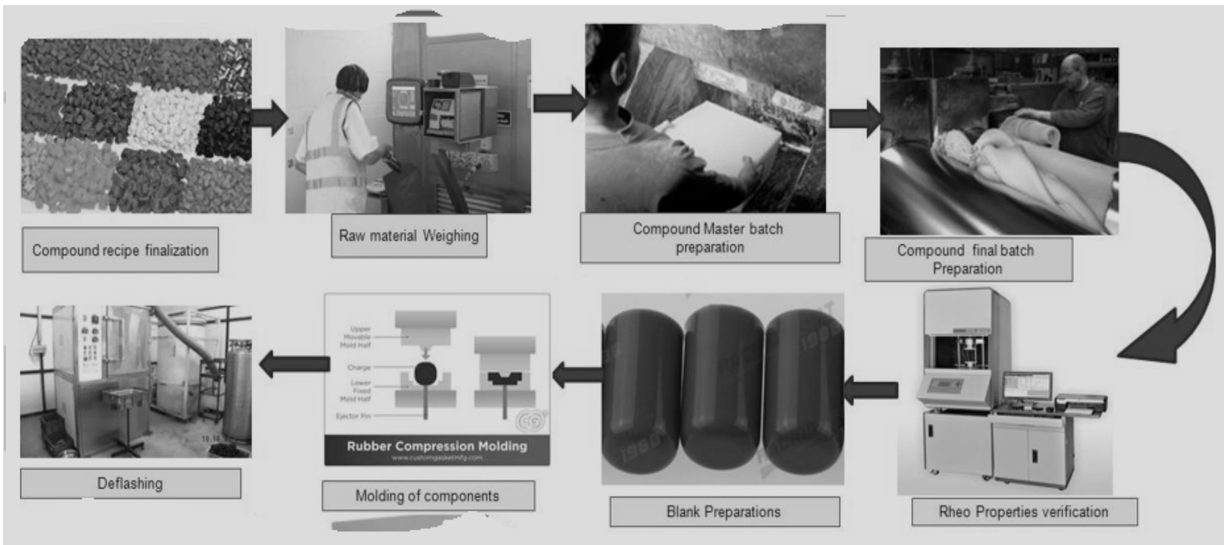


Figure 4. Oring manufacturing process flow

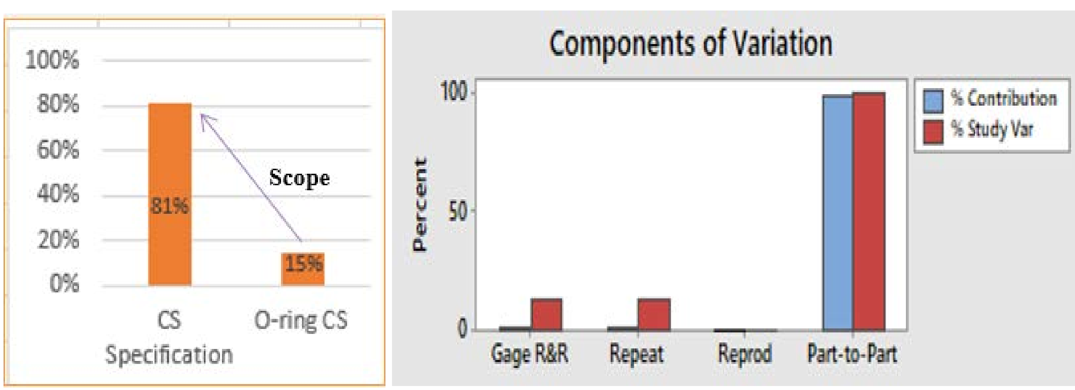


Figure 5. CS comparison graph

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.0017386	0.0104316	13.08
Repeatability	0.0017386	0.0104316	13.08
Reproducibility	0.0000000	0.0000000	0.00
appraiser	0.0000000	0.0000000	0.00
Part-To-Part	0.0131728	0.0790368	99.14
Total Variation	0.0132870	0.0797222	100.00

Number of Distinct Categories = 10

Figure 6. “Gage R&R for Dial thickness gauge”

B. Analyze phase

A cause and effect analysis were conducted by the cross functional team that comprises subject matter expertise of various departments to identify the potential root causes for the lower compression set in the rubber compounding recipe. “Figure 7” shows the analysis, subsequently a matrix was being developed per “table-10” showing the primary contributors. Finally three primary factors (‘X” inputs) were identified contributing to lower compression set (‘Y” output) were determined. *ACN content, process oil dosage and Sulphur level* are the three factors taken up for further experiments.

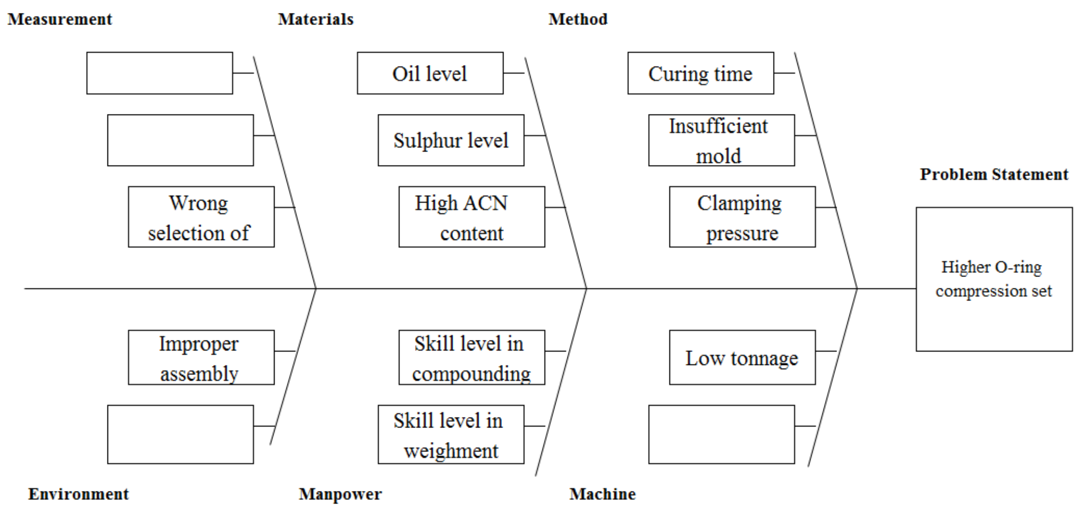


Figure 7. “Cause and effect analysis”

Table 2. Cause and Effect Matrix

Process Step	Process Inputs	Product to meet higher CS	Meet other requirements of the O-ring	Required meet service life minimum 0.8 million	Compound to meet standards	Total
Compound recipe finalization	A C N Content	9	9	9	3	300
	Process Oil Dosage	9	9	9	3	300
	Sulphur Level	9	9	9	1	280
	Curative Level	3	3	3	3	120
	Filler Selection	1	1	3	3	80
Process	Curing Time	4	1	1	1	70

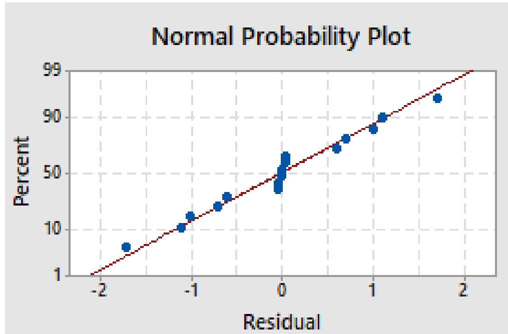


Figure 8. Normality plot

Target CS would be 20-25% as current level is 15%. Two levels for each factor is considered for DOE. Proposed ACN content level (25% existing) is 19.5% & 22.5%, process oil dosage would be 20 & 25 PHR (15 PHR existing) and Sulphur level 0.25 & 0.5 PHR (1 PHR existing). A *2^3 factorial design with 2 replicate were chosen*, trials were conducted and subsequent compression set responses were recorded. Normality plot Figure 8 graph looks normal, Three-way interaction P value ends insignificant around 0.94. Two-way interaction P value resulted significant less than 0.05. Main effect plot confirms the same, ACN content factor's contribution to compression set is very less and the same shall be ignored. Sulphur level and Oil dosage confirms as key factors, Interaction plot shows there is interaction between the two variables. Based on the output of interaction plot, *Sulphur level 0.25 PHR, Oil dosage 20*

Factor	Levels	Values
ACN content	2	19.5, 22.5
Oil dosage	2	20, 25
sulphur level	2	0.25, 0.50

Analysis of Variance

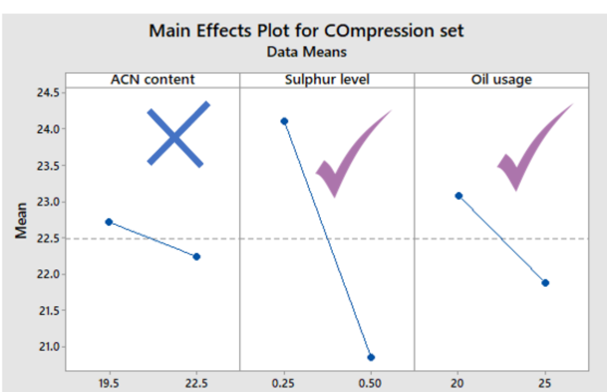
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	101.376	14.4823	9.55	0.002
Linear	3	85.610	28.5366	18.82	0.001
ACN content	1	0.946	0.9458	0.62	0.452
Oil dosage	1	5.676	5.6763	3.74	0.089
sulphur level	1	78.988	78.9877	52.10	0.000
2-Way Interactions	3	15.743	5.2477	3.46	0.071
ACN content*Oil dosage	1	0.628	0.6281	0.41	0.538
ACN content*sulphur level	1	0.002	0.0023	0.00	0.970
Oil dosage*sulphur level	1	15.113	15.1127	9.97	0.013
3-Way Interactions	1	0.023	0.0233	0.02	0.904
ACN content*Oil dosage*sulphur level	1	0.023	0.0233	0.02	0.904
Error	8	12.128	1.5160		
Total	15	113.504			

Factor	Levels	Values
ACN content	2	19.5, 22.5
Oil dosage	2	20, 25
sulphur level	2	0.25, 0.50

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	101.353	16.8921	12.51	0.001
Linear	3	85.610	28.5366	21.14	0.000
ACN content	1	0.946	0.9458	0.70	0.424
Oil dosage	1	5.676	5.6763	4.20	0.071
sulphur level	1	78.988	78.9877	58.50	0.000
2-Way Interactions	3	15.743	5.2477	3.89	0.049
ACN content*Oil dosage	1	0.628	0.6281	0.47	0.512
ACN content*sulphur level	1	0.002	0.0023	0.00	0.968
Oil dosage*sulphur level	1	15.113	15.1127	11.19	0.009
Error	9	12.151	1.3502		
Lack-of-Fit	1	0.023	0.0233	0.02	0.904
Pure Error	8	12.128	1.5160		
Total	15	113.504			

Figure 9. "DOE results3-way, 2-way interaction"



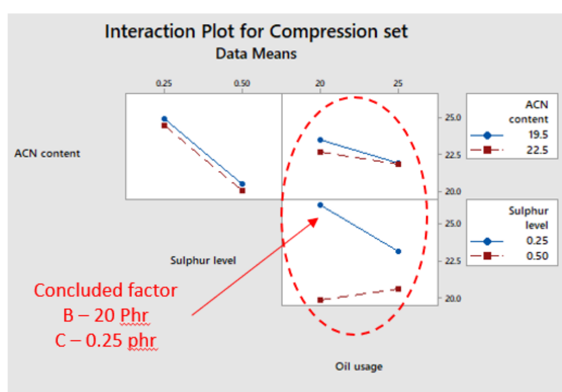


Figure 10. "Main effects and interaction plot"

PHR are concluded to be the new compound formulation design for piston O-rings AM application. Refer “Figure 9” and “Figure 10” illustrates DOE results and subsequent interaction plots.

C. Improve phase

Further to the defined new compound formulation in the earlier analyze phase, it’s vital to confirm same results in mass production and ensure the process follows a normal distribution. Two distinct trials were planned at various intervals. Materials were prepared with new formulations, productions took over and 15 samples were measured for compression set values each trial lot separately. Normality graph were plotted to study the results. At 95% confidence interval, the mean compression set of products recorded 32- 38%.Further to understand the significance between the trial lot results, a two-sample t-test were conducted. A MS-excel based two sample t-test were plotted to confirm significance between the sample lots. P-value resulted significant, as the mean difference were high. It was observed 10% max mean difference accepted per industry standards. “Figure 11” shows the t-test results. “Figure 12” comprises the normality graphs of two lots showing the mean at 32-38%.

t-Test: Two-Sample Assuming Equal Variances		
	Compression set Lot 1	Compression set Lot 2
Mean	34.06713333	37.56033333
Variance	4.16915241	3.655486238
Observations	15	15
Pooled Variance	3.912319324	
Hypothesized Mean Difference	0	
df	28	
t Stat	-4.836563965	
P(T<=t) one-tail	2.16794E-05	
t Critical one-tail	1.701130934	
P(T<=t) two-tail	0.000043359	
t Critical two-tail	2.048407142	

Figure 11. “Two sample T-test result”

With the satisfactory results of new formulation, accelerated endurance testing were carried out to confirm the life cycles of the new O-rings. It was observed that the leak in the system detected during 0.75 m cycles. (Target min were 0.8 m cycles, existing OE O-rings 1.3 m cycles). As the difference in “m” cycles are not significant for AM application, it’s been agreed by all to implement the same in the production and to observe the results over a period of time.

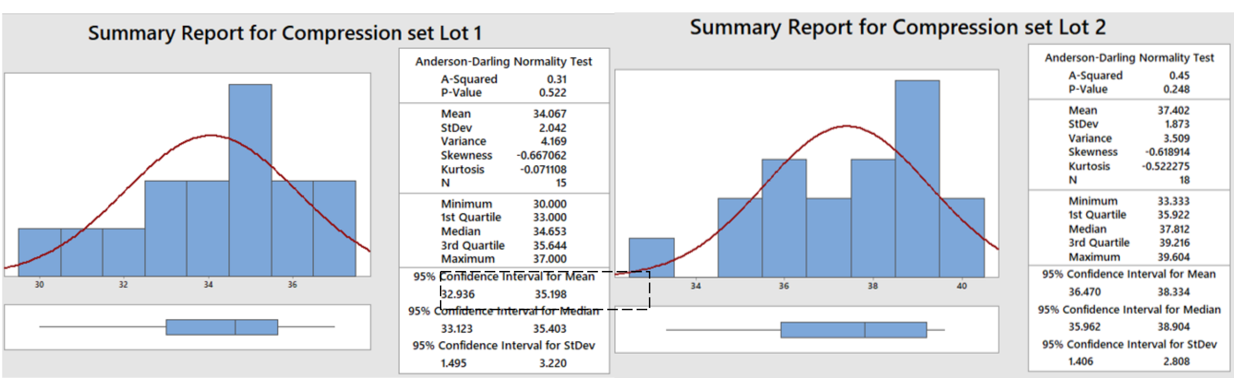


Figure 12. Normality test plot for two production lots

D. Control phase

The focus of this phase is to make sure that the changes incorporated in the existing process is well implemented and maintained. Here as the material formulations are changed, all the process and performance parameters to be validated against the new material formulation. Few main set of parameters includes Rheo properties for Rubber, mechanical properties like tensile, elongations, chemical properties for better flow ability during molding processes, abrasion properties for better assembly functions etc. In most of the cases an SPC study would be carried out to prove the performance and process capabilities. Part "density" is the key measurable item in rubber products. This would be the parameter that would be quoted for cost/prize purpose as well as customer end checking parameter. A process capability study of 'density of the new parts' is carried out. "Figure 13" confirms the "Cpk" value of 2.14 (above 5 sigma level) which confirms the process is stable.

A final process sign-off sheet was carried over as the final step of the six-sigma project followed by the manufacturing unit. The sheet primarily includes monitoring plan as to "who, what, when and how" monitor the outcomes in the production post implementation of the changes. Other key items in the sign-off sheet includes response plan, process standardization if any process parameters are changed to suit the new material etc. And finally transfer of ownership as to who owns the process once the six-sigma project team completes the project. Along with the sign-off sheet, a cost realization calculation was being undertaken as the part of final report to the management. The figure shall be agreed upon the finance department as they are the owner of the total cost function. The final project *annual saving figure ended with $ 40720. Six sigma project cost was $ 4500.* The savings from this six-sigma project contributed to achieve the overall business objective of reducing the cost of relay valves for AM application.

	Density	
	Specification: 1.22±0.02 g/cc	
Sample observation	1.212	1.212
	1.208	1.212
	1.212	1.212
	1.211	1.214
	1.212	1.213
	1.212	1.209
	1.207	1.208
	1.208	1.21
	1.213	1.21
	1.212	1.22

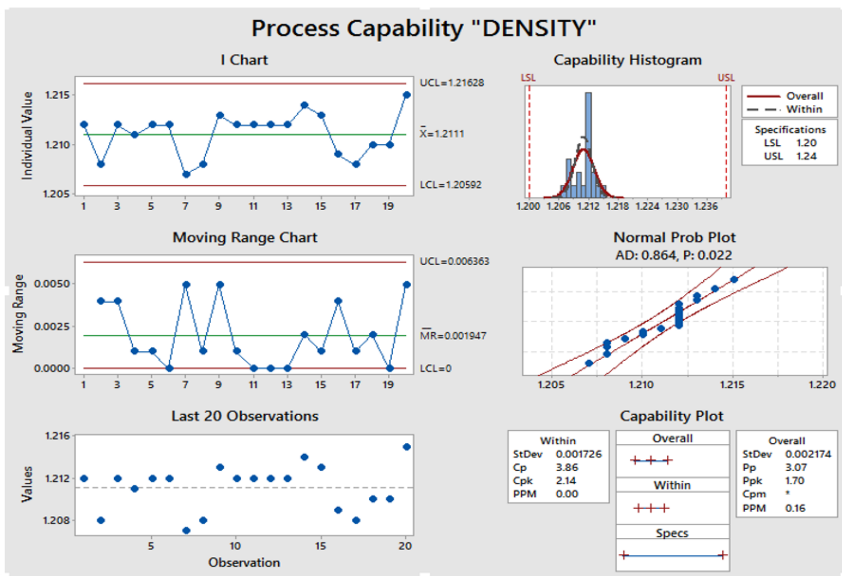


Figure 13. SPC study for "density"

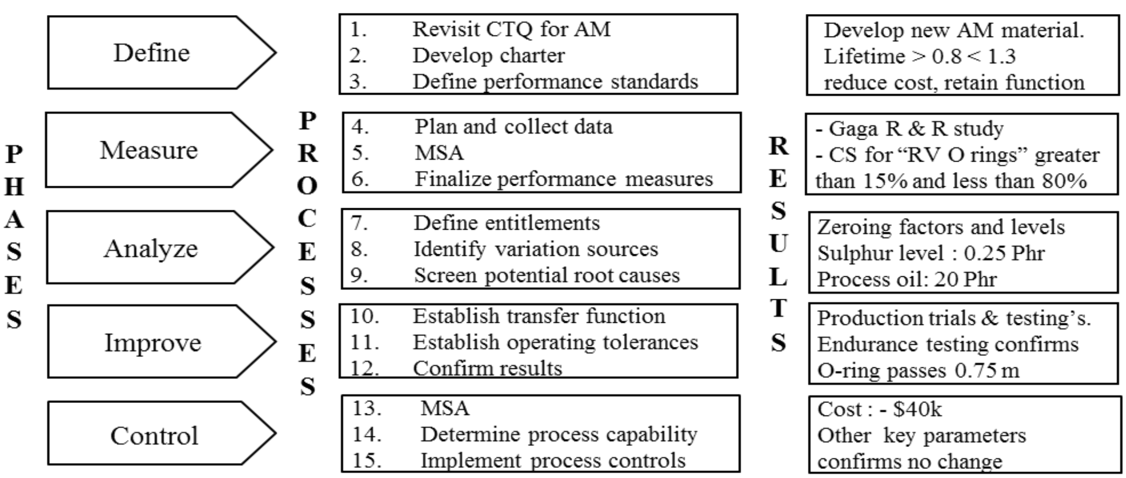


Figure 14. Phase deliveries

III. Conclusion

Six Sigma is an effective tool that would enable us to achieve improved performance and eventually drive us closer to operational excellence. While on the initial observation of the cost wise contributor Pareto of the valve assembly, the O-ring contribution was substantially less. However considering quick turnaround projects and realization of money, smaller parts like O-rings plays a key role in larger assemblies. “Figure 14” comprises the outcomes of each phases of project, a kind of plan vs actual report. This project would again emphasis on selection of appropriate six sigma project is key to the success of the project.

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Biographies

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