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Research Article

DEVELOPMENT OF EMPIRICAL FORMULAS FOR LPG CYLINDER ACCEPTANCE TEST PARAMETERS

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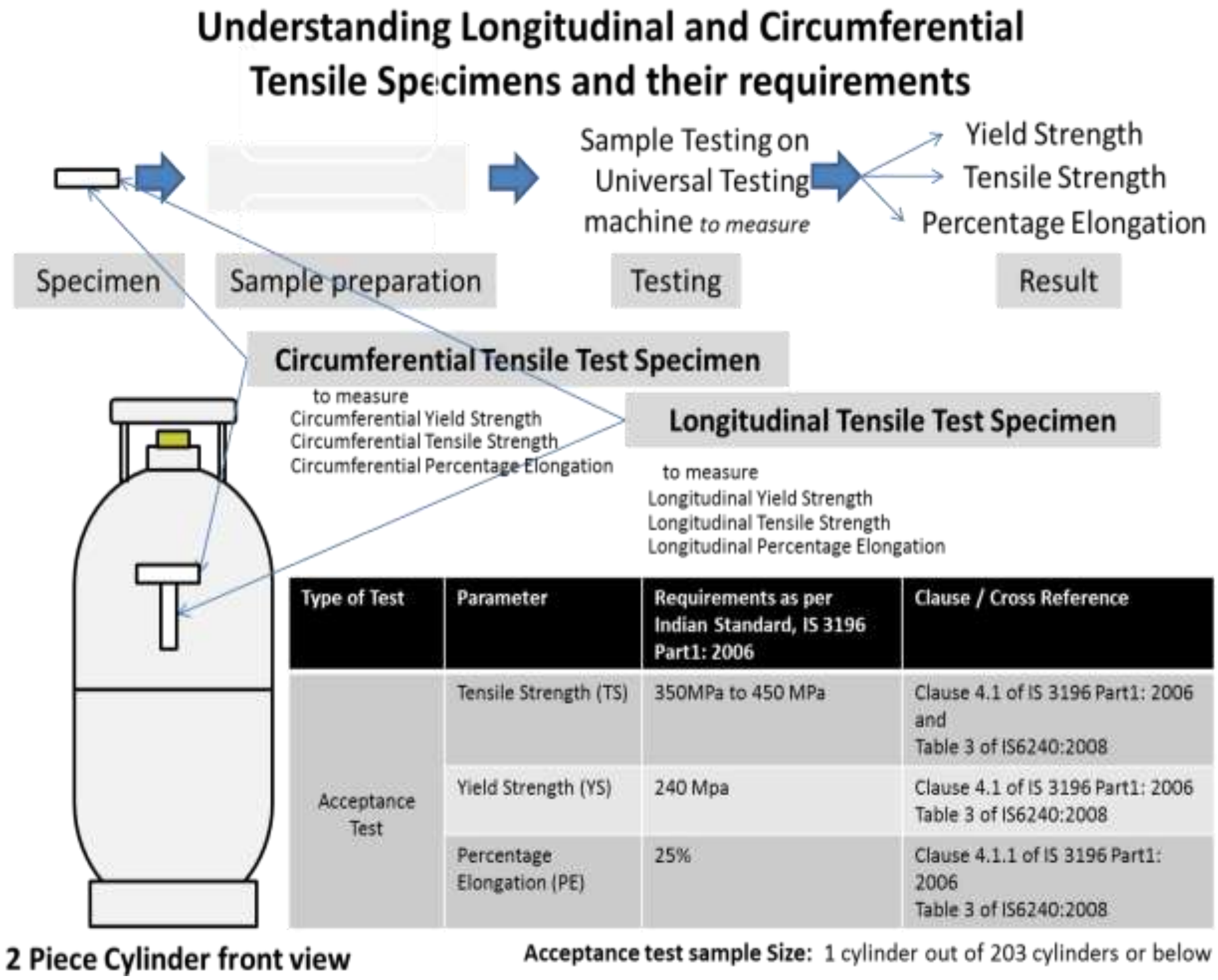
ABSTRACT
Liquefied Petroleum Gas cylinders are subjected to various tests at manufacturing locations to ensure their compliance requirements as per Indian standard IS 3196. Acceptance test is one of the important tests, in which LPG cylinder parent metal physical properties are measured. Two tensile samples are cut from a sample LPG cylinders and test for critical parameters of cylinder parent metal viz. yield strength, tensile strength and percentage elongation in both longitudinal and transverse (also called as circumferential) directions of cylinders. These values should meet the requirements given in standard to get Bureau of Indian Standards certification. All these critical properties are interrelated and exhibit certain correlations among themselves. In this paper an attempt has been made to establish various correlations among these variables and develop empirical formulas to estimate these parameters using 55 cylinders acceptance test data. Estimated values of these critical parameters from empirical formulas are analysed with appropriate reasoning. These empirical formulas can be used for estimating indicative parent metal physical properties without conducting a destructive test on cylinder.

Keywords: *Empirical Formulas, Acceptance Test, LPG Cylinders Testing, IS 3196*

INTRODUCTION
Acceptance tests are mandatory tests as per statutory authorities, conducted on Liquefied Petroleum Gas (LPG) cylinders in manufacturing location when new cylinders are produced as per Indian standard, IS 3196 (Indian Standard, 2006; Indian Standard, 2012). For every batch of 203 cylinders or less produced in a manufacturing location, one cylinder must undergo the acceptance test (Indian Standard, 2012). As a part of this test, a sample cylinder is selected from a manufactured batch and two tensile samples are cut from the body of this cylinder; one in longitudinal direction and the other in transverse direction or circumferential direction for testing purpose (Indian Standard, 2006). The tensile samples are tested on a universal testing machine to obtain physical properties of LPG Cylinder material (Indian Standard, 2012). That is from this test; Longitudinal Tensile Strength (LTS), Longitudinal Yield Strength (LYS), Longitudinal Percentage Elongation (LPE), Circumferential Tensile Strength (CTS), Circumferential Yield Strength (CYS) and Circumferential Percentage Elongation (CPE) of cylinder material can be measured. These parameters are checked against standard requirements to pass a freshly manufactured cylinder batch in manufacturing location (Indian Standard (1999; Indian Standard, 2006; Indian Standard, 2012). LPG cylinders are produced from a definitely prescribed raw material and batch production methods are implemented for producing a specific batch (Indian Standard, 2006). Hence it is expected that all cylinders in a batch are identical and having similar physical properties. These properties are revealed from a sample cylinder subjected to acceptance test and the values are attributed to all other cylinders in the batch (See Figure 1). It is evident by experience that these physical properties exhibit certain relations among themselves. However, there is no specific study on this correlation for cylinder parent metal. An attempt has been made in this research to study 55 cylinders acceptance test data to develop correlations and to establish empirical relation among these physical properties. It is expected to estimate the physical properties of cylinder material with these empirical formulas without destroying a cylinder or without conducting a destructive test on LPG cylinder.



Type of Test	Parameter	Requirements as per Indian Standard, IS 3196 Part1: 2006	Clause / Cross Reference
Acceptance Test	Tensile Strength (TS)	350MPa to 450 MPa	Clause 4.1 of IS 3196 Part1: 2006 and Table 3 of IS6240:2008
	Yield Strength (YS)	240 Mpa	Clause 4.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008
	Percentage Elongation (PE)	25%	Clause 4.1.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008

Figure 1: Acceptance tests of LPG Cylinders-Critical parameters and their requirements as per Indian Standards

MATERIALS AND METHODS

Data Collection

Domestic LPG Cylinders of 33.3 litre water capacity are selected to check the correlations among the critical parameters of cylinder material. These cylinders are most common type of cylinders in India and are constructed in two piece construction (Indian Standard, 2006). 55 such random cylinders acceptance test data from a Bureau of Indian Standards (BIS) approved and National Accreditation Board of Laboratories (NABL) accredited laboratories is collected for analysis purpose. These cylinders are manufactured from several manufacturers in India and are tested and certified as per IS 3196.

RESULTS

Minitab16, Microsoft windows based a statistical analysis software is used for analysis purpose in this study. Acceptance results are tabulated in terms of Longitudinal Tensile Strength (LTS), Longitudinal Yield Strength (LYS), Longitudinal Percentage Elongation (LPE), Circumferential Tensile Strength (CTS), Circumferential Yield Strength (CYS) and Circumferential Percentage Elongation (CPE) and correlation study was carried out between selected pairs. The pairs for the correlation study are identified as per Figure 2. Referring to the Figure 2, tensile strength or yield strength can be estimated from three different ways, whereas percentage elongation can be obtained in four different ways. The reasoning for this is clearly discussed in subsequent parts of this paper (discussion section). Pearson correlation constants for the identified pairs are calculated using Minitab16 and tabulated in Table.1. Trend analysis also carried out among these variables and they are all linear. Hence, regression analysis was carried out to establish linear equations among these critical parameters. The results of the regression analysis are tabulated in Table.2. These are the empirical formulas for all critical parameters of acceptance test, where in the units of tensile strength and yield strength are in MPa and the percentage elongation is in percentage.

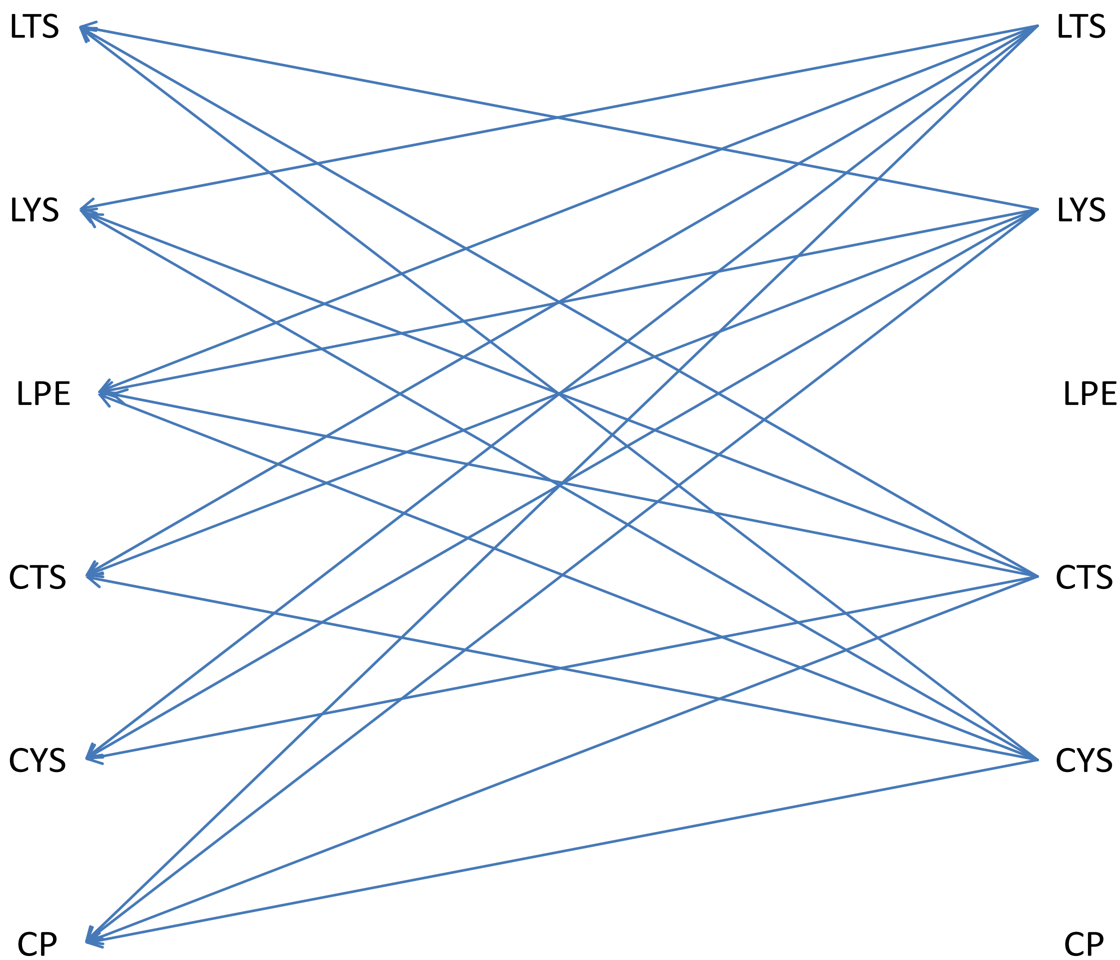


Figure 2: Possible Correlations among various acceptance test parameters of LPG Cylinder Parent metal

Table 1: Correlation Analysis on Acceptance test parameters

Pearson Correlation constants Vs.	LTS	LYS	CTS	CYS
LTS		0.559	0.760	0.280
LYS	0.559		0.320	0.470
LPE	-0.491	-0.232	-0.434	-0.328
CTS	0.760	0.320		0.126
CYS	0.280	0.470	0.126	
CPE	-0.503	-0.101	-0.627	-0.188

Table 2: Regression Analysis on Acceptance test parameters

Regression analysis plan

Vs.	**LTS**	**LYS**	**CTS**	**CYS**
LTS		LTS = X_{10} + Y_{10} LYS	LTS = X_{11} + Y_{11} CTS	LTS = X_{12} + Y_{12} CYS
LYS	LYS = X_{13} + Y_{13} LTS		LYS = X_{14} + Y_{14} CTS	LYS = X_{15} + Y_{15} CYS
LPE	LPE = X_{16} + Y_{16} LTS	LPE = X_{17} + Y_{17} LYS	LPE = X_{18} + Y_{18} CTS	LPE = X_{19} + Y_{19} CYS
CTS	CTS = X_{20} + Y_{20} LTS	CTS = X_{21} + Y_{21} LYS		CTS = X_{22} + Y_{22} CYS
CYS	CYS = X_{23} + Y_{23} LTS	CYS = X_{24} + Y_{24} LYS	CYS= X_{25} + Y_{25} CTS	
CPE	CPE = X_{26} + Y_{26} LTS	CPE = X_{27} + Y_{27} LYS	CPE= X_{28} + Y_{28} CTS	CPE = X_{29} + Y_{29} CYS

Regression Equations / Empirical Formulas

Vs.	**LTS**	**LYS**	**CTS**	**CYS**
LTS		LTS = 235.637+0.50628 LYS	LTS = 76.4299+0.797551 CTS	LTS = 271.134+0.386446 CYS
LYS	LYS = 37.7161+0.616944 LTS		LYS = 129.53+0.370893 CTS	LYS = 82.0919+0.716688 CYS
LPE	LPE = 86.3641-0.125995 LTS	LPE = 54.0581-0.0539602 LYS	LPE = 82.7526-0.116813 CTS	LPE = 69.5775-0.116307 CYS
CTS	CTS = 100.106+0.724902 LTS	CTS = 294.98+0.27664 LYS		CTS = 325.931+0.166194 CYS
CYS	CYS = 182.075+0.202164 LTS	CYS = 175.044+0.307674 LYS	CYS = 221.702+0.0956556 CTS	
CPE	CPE = 95.0519-0.14292 LTS	CPE = 49.03-0.0259937 LYS	CPE = 110.901-0.186611 CTS	CPE = 61.0831-0.0738395 CYS

DISCUSSION

Referring to Figure 2, the basis for possible correlation pairs are justified here. Tensile strength and yield strength can be obtained directly from tensile test whereas the percentage elongation is calculated after the test by keeping the broken samples together (Indian Standard, 2012). It means, while calculating the tensile strength and yield strength the error due to experiment is minimal. On the other hand, the possibility is very high in case of percentage elongation and hence, percentage elongation can be estimated from tensile strength and yield strength whereas tensile strength and yield strength is not possible to estimate using elongation values. In simple terms, referring to Figure 2 suppose, if LTS to be estimated, it can be calculated form LYS, CTS or CYS but no from LPE or CPE whereas, LPE can be estimated from any one of the parameters LYS, LTS, CYS, CTS and not from LPE or CPE. Further, LPG Cylinders are manufactured with low carbon steel with definitely prescribed raw material for construction (Indian Standard, 2012). The relation between tensile strength and yield strength are proportional (Indian Standard, 1991; Akula *et al.*, 2013; Gajko and Rosenberg) and the relation between tensile strength and the percentage elongation is inverse relation (Indian Standard, 1991) in low carbon steel. In simple terms, higher the tensile strength, lower the percentage elongation in a low carbon steel. Also, from the literature it is established that a circumferential tensile sample exhibits less tensile strength and yield strength than a longitudinal sample (Akula *et al.*, 2013). On the other hand, circumferential sample exhibits more percentage elongation than a longitudinal sample (Akula *et al.*, 2013). Keeping all these possibilities and relations in mind, empirical formulas are generated using linear quadratic equations.

Values of all critical parameters are estimated using the empirical formulas and box plots were generated for comparison of actual values with estimated values. For example, referring to Figure 3, LTS was estimated using LYS, CTS, CYS and compared with LTS actual values with estimated LTS values obtained from LYS, CTS and CYS as ELTS, ECTS and ECYS. Similarly for all other critical parameters, LYS, LPE, CTS, CYS, and CPE are estimated and compared with actual values using the box plots from Figure 3 to Figure 8.

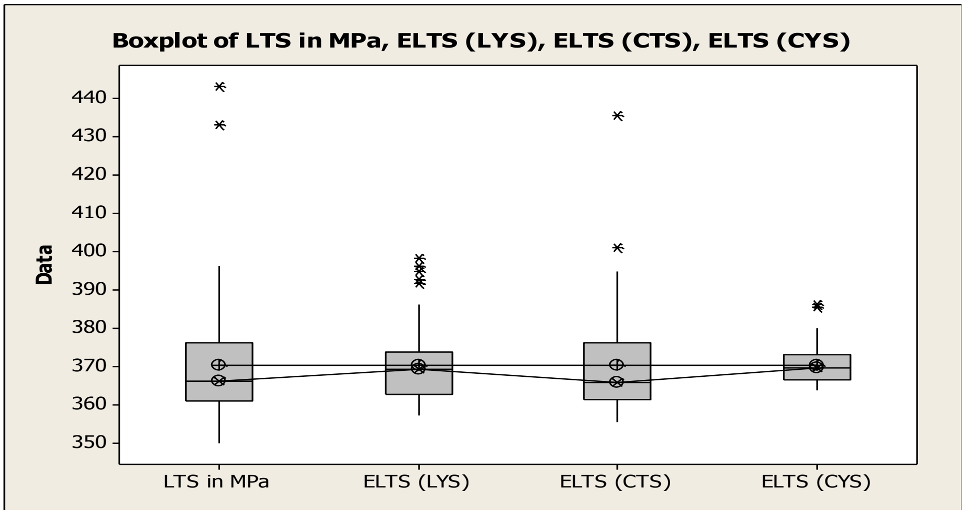


Figure 3: Comparison of actual and estimated values of Longitudinal Tensile Strength values

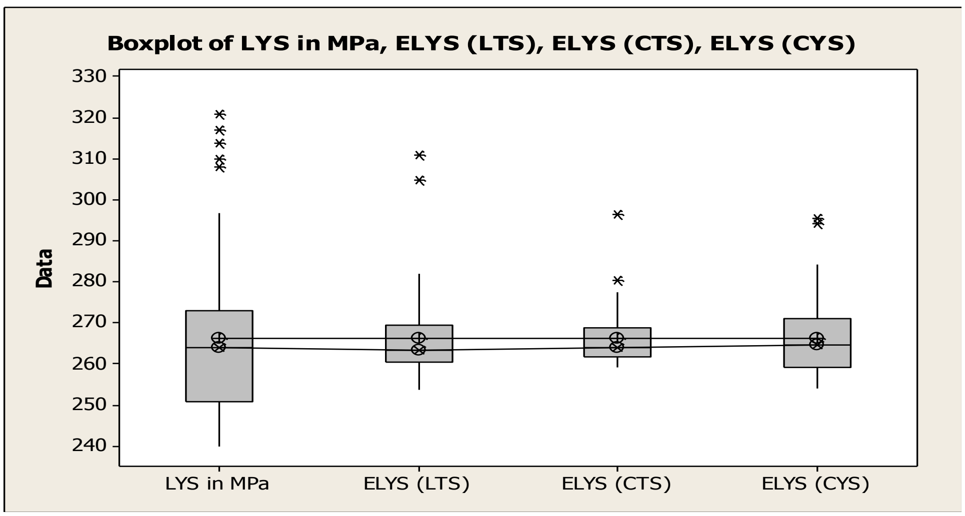


Figure 4: Comparison of actual and estimated values of Longitudinal Yield strength values

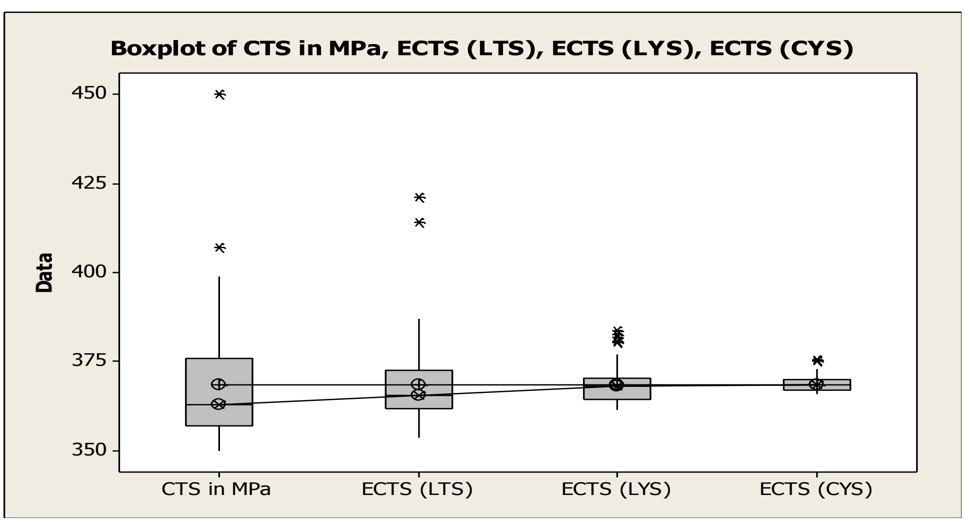


Figure 5: Comparison of actual and estimated values of Circumferential Tensile Strength values

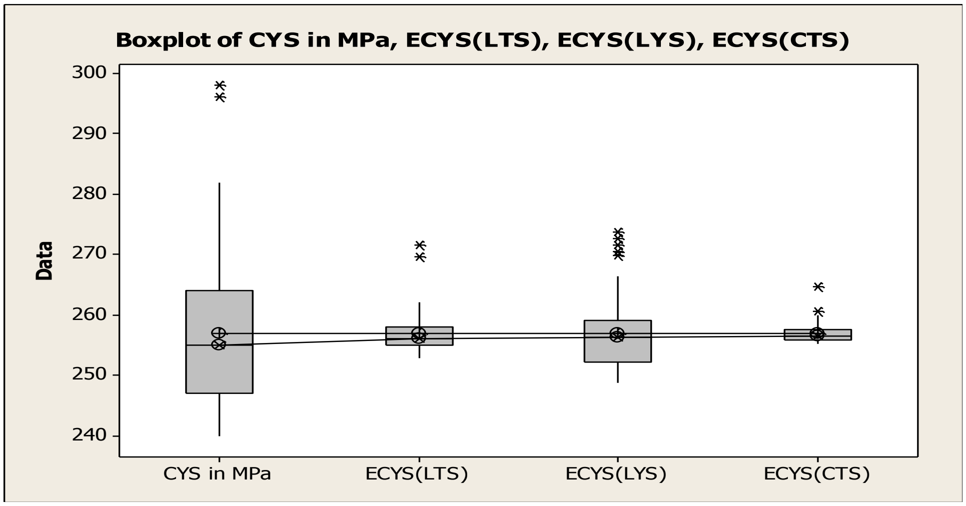


Figure 6: Comparison of actual and estimated values of Circumferential Yield Strength values

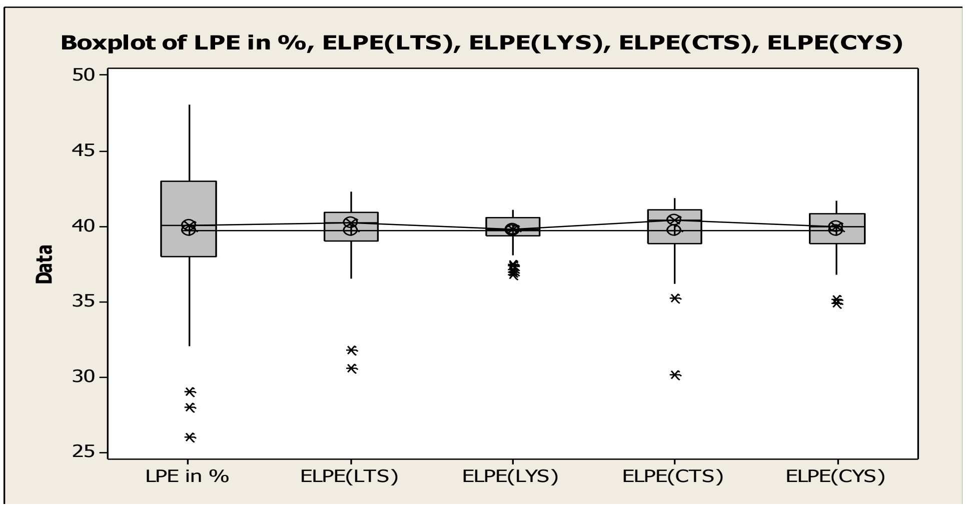


Figure 7: Comparison of actual and estimated values of Longitudinal Percentage Elongation values

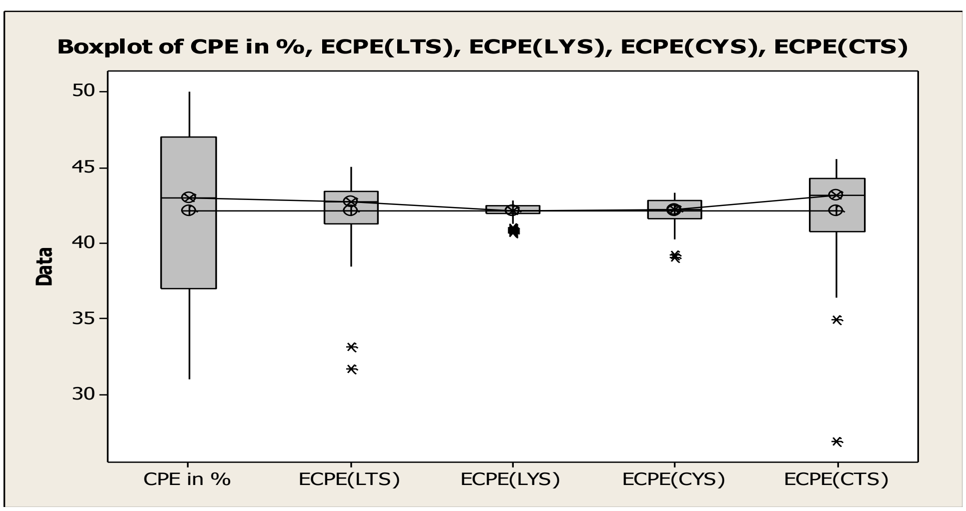


Figure 8: Comparison of actual and estimated values of Circumferential Percentage Elongation values

Although the mean connect lines are matching with both actual and estimated values in all box plots, the median connect lines are not in line with actual values because of the regression equations of the estimates. It is observed that the interquartile range boxes are more or less compressed in all estimated results in all the boxplots. Wherever such compression is observed, it indicates lean relationship among those specific pairs. For example, referring to Figure 3 LTS can be estimated LYS, CTS and CYS. However CTS Estimates are close to the LTS actual values and the estimate for LTS is more appropriate from CTS and least appropriate from CYS. Similarly for estimating LYS, CTS and CYS; CYS, LTS and LYS values are more appropriate whereas for estimating LPE and CPE, CTS is more appropriate. Thus following empirical values can be considered for estimating critical parameters of cylinder parent material

1. LTS = 76.4299 + 0.797551 x CTS
2. LYS = 82.0919 + 0.716688 x CYS
3. CTS = 100.106 + 0.724902 x LTS
4. CYS = 182.075 + 0.202164 x LTS
5. LPE = 82.7526 – 0.116813 x CTS
6. CPE = 110.901 – 0.186611 x CTS

This compressed interquartile range box in all boxplots also indicates that the range of estimates is limited to certain levels because of the sample data type. In case a set of failure cylinder data is considered for empirical formula generation, this range could expand to the levels of actual values. There are certain out layers observed in boxplots are due to certain values of the data are beyond the normal. Range this is possible due to sample data type, and sample preparation process (Akula *et al.*, 2013). Also, the Pearson correlation constants of certain pairs are not showing very strong correlation in Table.1. Weak correlations are possible due to various reasons like raw material selection, cylinder manufacturing process, welding methods adopted while fabricating cylinders, Heat treatment process parameters to relieve internal stresses in cylinders due to welding operation, Sample test methods etc (George, 1976; Akula *et al.*, 2013; Akula *et al.*, 2013; Akula *et al.*, 2013). In the current study, the samples are collected from various manufacturers in India, produced their cylinders with minor variations in raw material sourced from various steel mills in India. Indian standard doesn't specify explicit manufacturing process, test method, heat treatment process parameters, sample test methods (Indian Standard, 2006; Indian Standard, 2012). However, it states the finished cylinder should meet certain conditions for Bureau of Indian Standards certification (Indian Standard, 2006). This is mainly to accommodate several manufacturers in India for producing approximately 18 million cylinders in a year to meet the current Indian market demand (Presentation, 2010). Also, it is practically not possible to get failed cylinder test data for analysis purpose and to develop a mathematical model. The cylinder data available in any BIS approved laboratory is only from accepted or passed cylinder segment. Thus the failure cylinder test data is not included in this study for empirical formula generation purpose. In addition to that, the test set up, sample preparation can also leads inadvertent mistakes some times, especially while calculating yield strength and percentage elongation (Akula *et al.*, 2013).

It is evident from the work; empirical formulas can be established among the critical variables of cylinder acceptance test parameters. However, to improve the accuracy of empirical formulas, it is necessary to consider failure cylinders test data in addition to the passed cylinders test data for analysis purpose. Further, the data used for the analysis purpose should be from a controlled manufacturing and test conditions. It means very accurate the empirical formulas can be established, if the raw material, manufacturing process, heat treatment parameters and welding methods are standardised for LPG cylinder manufacturing. However, it is practically not possible, keeping in view of the existing cylinder manufacturers' population and their productions setup (Bureau of Indian Standards, 2013). Thus the empirical formulas developed in this method can be used only for estimation purpose and cannot be implemented for replacing existing testing process mentioned in Indian standards.

LPG cylinders in use are tested and approved by BIS at the time of releasing them to market. The empirical formulas given in this work can provide indicative values of such cylinder for analysis purpose, as the test data used in deriving the empirical formulas is purely from such cylinders.

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Conclusion

55 domestic LPG cylinder test results are fed to Minitab 16 and developed empirical formulas to estimate acceptance test parameters of LPG Cylinder parent metal. Estimated and actual test values are analysed in the study using correlation study, trend analysis, regression analysis and by generating box plots. It is evident from the study, that the empirical formulas can be established among various LPG Cylinders acceptance test critical parameters. However, the accuracy of these empirical formulas are grossly depends on raw material selection, manufacturing methods, heat treatment process parameters, test methods etc. While developing empirical formulas, it is necessary to include failure test data for accurate empirical formulas to increase the range of estimated values. The empirical formulas given in this paper can be used for indicative purpose and not intended for replacing the existing test methods prescribed in Indian standards.

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