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***Research Article***

# ESTIMATION OF LPG CYLINDER PARENT METAL YIELD STRENGTH AND TENSILE STRENGTH FROM HARDNESS VALUES

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## ABSTRACT
Liquefied Petroleum Gas (LPG) cylinders plays critical role to contain and transport hazardous LPG in its lifecycle. LPG cylinders in India are designed, manufactured and tested as per Indian standard IS 3196 to ensure that they are safe and are compiled to minimum required specifications. LPG cylinders are produced in batches with definitely prescribed raw material and with same manufacturing process parameters including heat treatment process while producing a specific batch or lot. All such manufacture red lots should meet minimum specifications given in standard. It is necessary to conduct destructive tests on some of these cylinders during manufacturing process to measure critical properties of LPG Cylinder material. In this work an attempt has been made to estimate yield strength and tensile strength of cylinder material using hardness values. 55 number of domestic LPG Cylinders destructive test data is considered to develop empirical formulas for estimating yield and tensile values. Actual test data is compared with estimated values and suggested a best method for estimating the tensile and yield stress using cylinder hardness values. These empirical formulas can be used for estimating indicative tensile and yield strength values of parent metal without conducting a destructive test on LPG cylinder.

***Keywords:*** *LPG Cylinder, Yield Strength, Tensile Strength, LPG Cylinders, Acceptance Test and IS 3196*

## INTRODUCTION
LPG Cylinders in India are designed, manufactured and tested as per Indian standard IS 3196. These cylinders are produced in batches or lots from definitely prescribed raw material (IS6240 or equivalent) and with similar manufacturing process parameters for a specific lot while manufacturing. Once the cylinder lot is produced, one random cylinder is chosen from a lot of 203 or less to conduct acceptance test on LPG Cylinders. The acceptance test is to reveal parent metal physical properties such as yield strength, tensile strength and percentage elongation. In order to measure these parameters, two tensile samples are cut from LPG Cylinder; one in longitudinal and the other in transverse (circumferential) directions. These two tensile samples are subjected to tensile test to measure yield strength, tensile strength and percentage elongation. The values of these parameters are checked against the values given in standards to ensure the cylinders are meeting minimum requirements prescribed in standards. From the existing literature, it is evident that the circumferential tensile sample exhibits lower values of tensile and yield strength. Hence, the circumferential specimen test values are critical in a cylinder parent metal testing process to certify a cylinder batch. Although the sample size for testing the acceptance test in standard is too small (only 1 in 203 or less no of cylinder batch), it is impractical to destroy several cylinders for measuring these properties, when the manufacturing criteria for a specific batch is same. Also at the same time there is no other alternative method exists to estimate these values using empirical formulas or non-destructive test methods. Thus, it is not possible in the existing practice to measure the cylinder critical parameters once they are released to market from manufacturing location for usage.
LPG cylinders are produced from low carbon steel and from definitely prescribed raw material. From the literature, it is evident that yield strength and tensile strength can be estimated from hardness values of low carbon steels. Hardness, tensile strength and yield strength values of low carbon steel can be correlated. 55 Domestic LPG cylinders acceptance test data has been collected for analysis purpose in this study. Further hardness of cylinder material is measured with Brinells hardness testing machine.

Regression equations are developed based on trend analysis and correlation analysis for estimating tensile and yield strength. At the end of the estimated and actual values are compared and suggested best way to estimate yield strength and tensile strength from Hardness value of LPG Cylinder material.

## MATERIALS AND METHODS

### *Data Collection*

Acceptance test date of 55 domestic LPG Cylinders of 33.3 litre water capacity is used for developing the empirical formulas. These cylinders are most common type of cylinders in India and are constructed in two piece construction. These 55 cylinders are manufactured from several manufacturers in India and are tested and certified as per IS 3196. Bureau of Indian Standards (BIS) certified all these cylinders for use in market.

### *Experiments*

In order to measure hardness of LPG Cylinder a parent metal sample of 50mm x 50mm was cut from 55 domestic LPG cylinders and tested them on Brinells hardness testing machine to obtain BHN value of LPG cylinder material. Acceptance test data is collected from an authorized Bureau of Indian Standard Laboratory, having national accreditation board of laboratories (NABL) certification and the hardness test is conducted on the same lot of cylinders in a commercial laboratory having NABL accreditation for reliability of test results.

### *Analysis and 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), Circumferential Tensile Strength (CTS), and Circumferential Yield Strength (CYS) along with the hardness values of specific cylinders. Correlation study was carried out between selected pairs as per the Table1 and the person correlation constants were tabulated in the same table.

**Table 1: Empirical formulas for estimating Yield and tensile strength**

| Brinell Hardness Number (BHN) vs. | CTS | CYS | LTS | LYS |
|---|---|---|---|---|
| Correlation Pair | BHN Vs. CTS | BHN Vs. CYS | BHN Vs. LTS | BHN Vs. LYS |
| Pearson Correlation Constant | 0.034 | 0.238 | 0.261 | 0.246 |
| Trend Analysis | Proportional | Proportional | Proportional | Proportional |
| Possible Regression equation | $CTS = a_1+b_1\,BHN$ | $CYS = a_2+b_2\,BHN$ | $LTS = a_3+b_3\,BHN$ | $LYS = a_4+b_4\,BHN$ |
| Regression Equations / Empirical formula | CTS =358.93+0.069768 2x BHN | CYS =205.909+0.36696 2x BHN | LTS =292.834+0.557781 x BHN | LYS =185.675+0.57917 7x BHN |

In addition to the person correlation, trend analysis was carried out among these selected pairs and checked their relation whether there are proportional or inversely proportional. Both tensile and yield strength are proportional to hardness values and are linear. A linear equation was developed among the pairs using regression analysis keeping yield strength and tensile strength are dependent variables and the BHN as independent variable. Thus the empirical relation for measuring yield strength and tensile strength of longitudinal and circumferential specimen are obtained and are given below

CYS = 205.909 + 0.366962 x BHN
LTS = 292.834 + 0.557781 x BHN
LYS = 185.675 + 0.579177 x BHN
CTS = 358.93 + 0.0697682 x BHN

Yield strength and tensile strength are estimated using the above formulas with the known 55 values of BHN and compared the actual and estimated values using box plots for clear understanding of the results in graphical form. Figure 1 and Figure 2 shows the box plot of actual and estimated values of Circumferential Tensile and Yield Strengths. Similarly, Figure 3 and Figure 4 shows the actual and estimated values of Longitudinal Tensile and yield strengths.

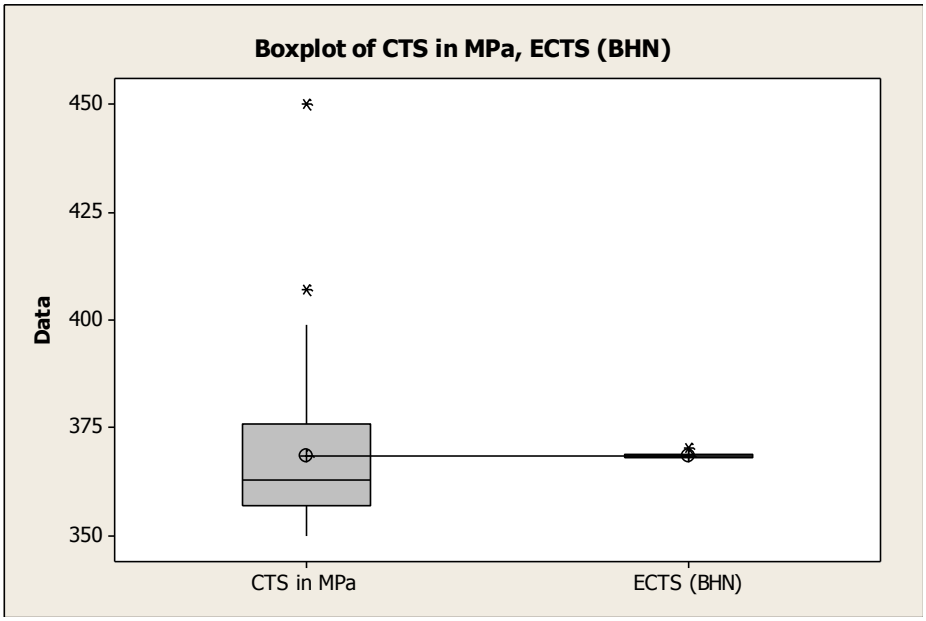


**Figure 1: Comparison of actual and estimated values of Circumferential Tensile Strength values**

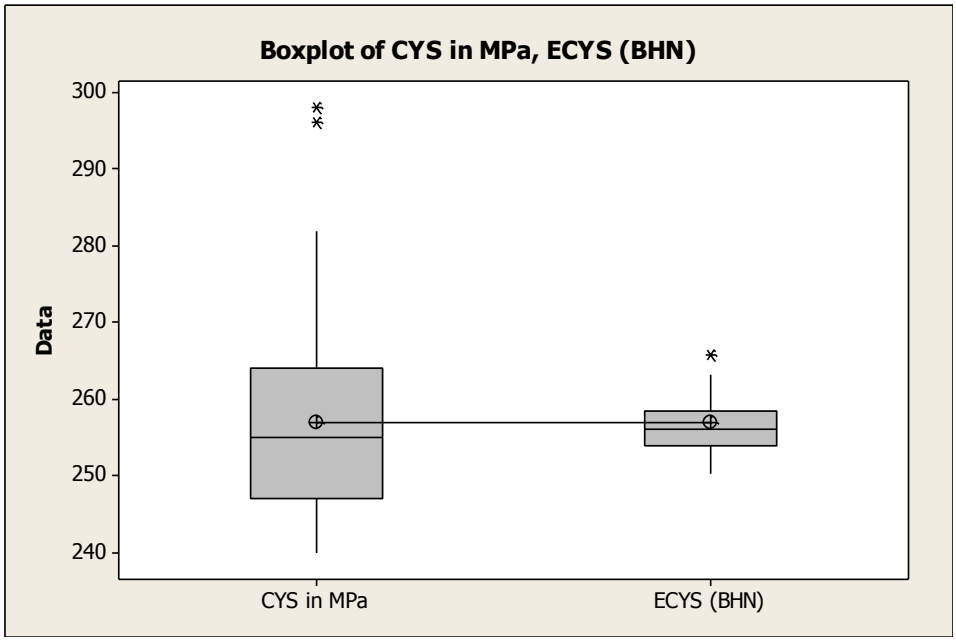


**Figure 2: Comparison of actual and estimated values of Circumferential Yield Strength values**

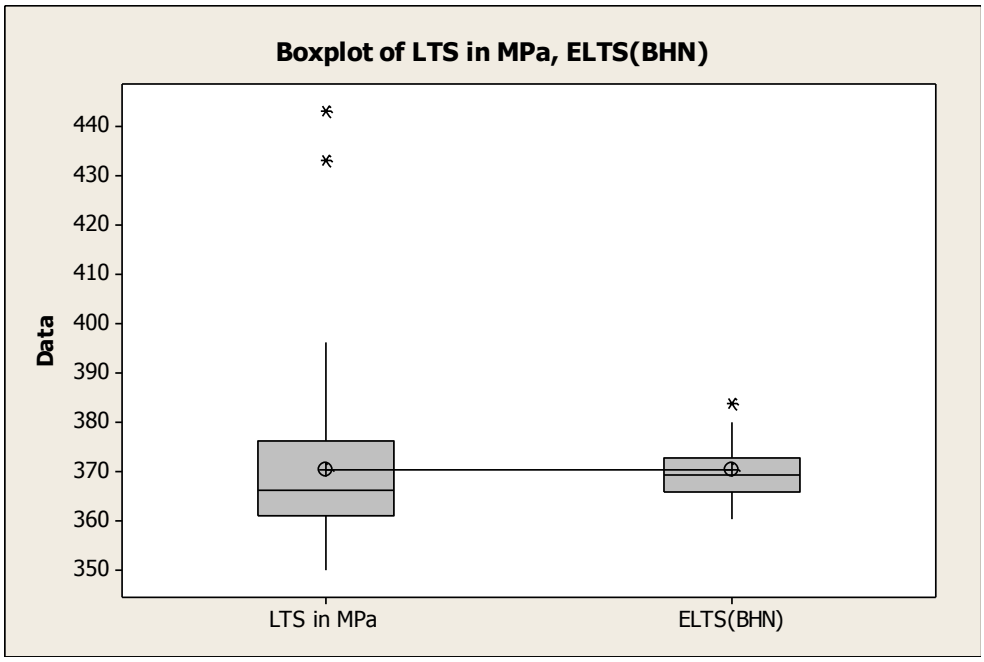


**Figure 3: Comparison of actual and estimated values of Longitudinal Tensile Strength values**

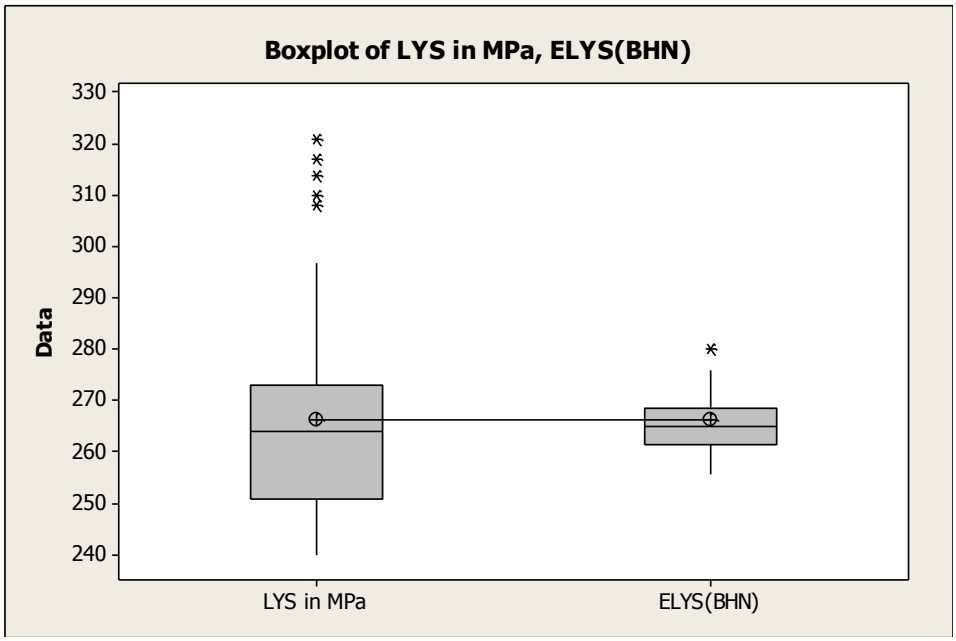


**Figure 4: Comparison of actual and estimated values of Longitudinal Yield strength values**

## DISCUSSION

Referring to the Figure 1 to Figure 4, Although the man connect lines are same for both estimated and actual values, the interquartile range boxes of box plots are compressed in estimated values. It means the estimated values are within close range of the interquartile range boxes of the estimated values shown in the box plots. However, the range is relative is better in LTS, LYS and CYS whereas the inter quartile range for CTS is almost flat. It means the estimated values are more or less same irrespective of the BHN values. Thus, this formula cannot be useful for estimating the CTS values using BHN. However, CYS,

LTS and LYS can be estimated with the given formulas. From the literature, it is evident that the circumferential samples exhibit lower values and are critical for accepting the batch. In the current study CYS is having moderate interquartile range box and can be used for estimating the value of minimum yield strength of LPG cylinder. According the existing literature, correlations can be established among various critical parameters of LPG Cylinder parent metal with any one of the yield strength or tensile strength as independent variable. From the current study, If CYS is obtained from BHN; these values can be used as independent variable and can estimate all other parameters of LPG Cylinder parent metal critical properties.

Although, strong correlation exist among, hardness, tensile strength and yield strength, the Pearson correlation constant in Table 1 doesn't exhibit this phenomenon with the identified test results. This is also evident in box plots with compressed inter quartile range boxes for the estimated values; especially for the circumferential tensile strength. The main reasons for this weak relation can be attributed to sample selection, manufacturing process, Heat treatment process parameters, test methods and testing setup and the skill of the operator for interpreting the test results for reporting purpose.

In the current study all the 55 samples are selected from various cylinder manufacturers across India. Currently more than 130 cylinder manufacturers are in India and are producing LPGcylinders as per Indian specifications. The specifications related to raw material given in standards are minimum. However the cylinder manufacturer can source the raw material from various steel mills across Indian and the parameters of raw material could be superior to the specification given in standard. This is possible when there is severe demand for the cylinders in market and also raw material movement (logistics) point of view. Thus, the cylinder manufacturers' uses different raw material with the range given and it could be one of the reason for variation in results.

Similarly, the standard doesn't explicitly specify the cylinder manufacturing methods. It states only the final product (cylinder) requirements. The product requirements can be met in various methods depending on the manufacturing set up. For example the standard states, any fusion welding method for welding operation, manufacturer can choose any welding methods depending on his production set up. Once the welding process is completed, the cylinders need to be heat treated to relieve the internal stresses generated due to welding process. Heat treatment process parameters may be different from one manufacturer to another as they have different kinds of furnaces. Also, the end product parameters are purely based on mill certificate of the raw material supplier. Thus raw material, manufacturing and heat treatment process parameters can affect the test results.

Sample preparation also affects the cylinder acceptance test results like for example; cold pressing during sample preparation can increase the strain hardening of the tensile specimen. Also gas cutting can increase the heat affected zone. Hand filing may cause irregular parallel lengths of specimen and that can affect the test results. In addition to that skill in identifying the yield point on stress strain graph and interpretation of standard for identifying the yield point also can affect the test results.

In the present study the above factors might have caused the variation in test results and the correlation constants are not in favour of strong relations. However, it is not practically possible to test 55 samples from same manufacturer with same manufacturing parameters as the acceptance test is conducted only on 203 cylinders or less ad hence in the current study the samples are collected from various manufacturers across India. Further, the interquartile ranges are compressed because the test results are from accepted lots and there is no failure cylinder data in it. Thus the estimated values are also in acceptance range. In order to increase the interquartile range box to the extent of actual values, it is necessary to include the failure data for regression analysis. However, it is highly impractical to get huge failure data for regression analysis. Keeping in view of the constraints to the practical results, the empirical formulas can be used to estimate indicative values of the cylinder material. From the study it is established that the empirical formulas can be developed however, the accuracy of the formulas is largely depends on various parameters mention in this chapter above. Thus these formulas can be used for indicative estimates only and not intended for replacing the existing test methods given in the standard.

***Conclusion***

The study focuses on establishing empirical relations among tensile strength, yield strength and hardness values of a cylinder material. 55 Domestic LPG cylinder acceptance test results are considered for developing the relations. Also all these cylinders are tested on Brinells hardness tester to get the hardness values. The results are correlated, and developed empirical relations to obtain yield strength and tensile strength from hardness values. Although it is evident that the relations are definite, several factors like raw material, manufacturing process, heat treatment process parameters, test sample preparation, testing methods, skill of the operator can affect the test results. The formulas given in the study can be used for estimating the values indicatively as a part of accident analysis of incident investigation. However, this cannot be used for replacing the existing test methods given in the standard.

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